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FORM PTO-1390 (REV 10-01-00) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER 40999
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S APPLICATION NO. (If known, see 37 CFR 1.5) 09/673271
INTERNATIONAL APPLICATION NO. PCT/EP98/02169	INTERNATIONAL FILING DATE 14 April 1998	PRIORITY DATE CLAIMED

TITLE OF INVENTION Frame Structure and Frame Synchronization for Multicarrier Systems

APPLICANT(S) FOR DO/EO/US
Ernst Eberlein, Sabah Badri, Stefan Lipp, Stephan Buchholz, Albert Heuberger, Heinz Gerhaeuser

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☑ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☑ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☑ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☑ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☑ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☑ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☑ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☑ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☑ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☑ Other items or information:

    (a) Copy of International Application as filed (14 April 1998).
    (b) Copy of International Search Report (14 January 1999).
    (c) Copy of Published International Application (21 October 1999).
    (d) Copy of International Preliminary Examination Report (9 February 2000).

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U.S. APPLICATION NO (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
09/673271	PCT/EP98/02169	40999

17. ☑ The following fees are submitted:

	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO .... **$1000.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO .... **$860.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO .... **$710.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) .... **$690.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 860.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☑ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$ 130.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	46 - 20 =	26	X **$18.00**	$ 468.00	
Independent claims	8 - 3 =	5	X **$80.00**	$ 400.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **$270.00**	$ 0.00	
TOTAL OF ABOVE CALCULATIONS =				$ 1,858.00	
Reduction of 1/2 for filing by small entity, if applicable. A Small Entity Statement must also by filed (Note 37 CFR 1.9, 1.27, 1.28).				$ (0.00)	
SUBTOTAL =				$ 1,858.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$ 0.00	
TOTAL NATIONAL FEE =				$ 1,858.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$ 0.00	
TOTAL FEES ENCLOSED =				$ 1,858.00	
				Amount to be refunded:	$
				charged:	$

a. ☑ A check in the amount of $ 1,858.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ______ in the amount of $______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☑ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 18-2220. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Roylance, Abrams, Berdo & Goodman, L.L.P.
1300 19th Street, N.W., Suite 600
Washington, DC 20036

John E. Holmes
SIGNATURE:

John E. Holmes
NAME

29,392
REGISTRATION NUMBER

09/673271

40999

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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	:	
	:	
Ernst Eberlein et al.	:	Group Art Unit:
	:	
Serial No.: Not Assigned	:	Examiner:
	:	
Filed: Herewith	:	
	:	
For: Frame Structure and Frame Synchronization for Multicarrier Systems	:	

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

This Preliminary Amendment is being filed concurrently with the U.S. national stage entry under 35 U.S.C. § 371 of International Application No. PCT/EP98/02169, which has an International Filing Date of April 14, 1998. Prior to examination and calculation of the filing fees, please amend the national stage application as follows:

IN THE SPECIFICATION:

Please delete the current specification, comprising pages 1-25 and 37 (as amended in the International Preliminary Examination Report dated February 9, 2000) and replace it with the accompanying substitute specification.

IN THE CLAIMS:

Please cancel claims 1-46 annexed to the International Preliminary Examination Report dated February 9, 2000, and substitute the following new claims 47-92:

47. A method for generating a signal having a frame structure, each frame of said frame structure comprising at least one useful symbol, a guard interval associated to said at least one useful symbol and a reference symbol, said method comprising the step of

performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of said reference symbol; and

inserting the amplitude modulated bit sequence into said signal as said reference symbol.

48. The method according to claim 47, wherein said signal is an orthogonal frequency division multiplexed signal.

49. The method according to claim 47, wherein said amplitude modulation is performed such that a mean amplitude of said reference symbol substantially corresponds to a mean amplitude of the remaining signal.

50. A method for generating a multi-carrier modulated signal having a frame structure, each frame of said frame structure comprising at least one useful symbol, a guard interval associated to said at least one useful symbol and a reference symbol, said method comprising the steps of:
providing a bitstream;
mapping bits of said bitstream to carriers in order to provide a sequence of spectra;
performing an inverse Fourier transform in order to provide multi-carrier modulated symbols;
associating a guard interval to each multi-carrier modulated symbol;
generating said reference symbol by performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of said reference symbol;
associating said reference symbol to a predetermined number of multi-carrier modulated symbols and associated guard intervals in order to define said frame; and
inserting said amplitude modulated bit sequence into said signal as said reference symbol.

51. The method according to claim 50, wherein said multi-carrier modulated signal is an orthogonal frequency division multiplex signal.

52. The method according to claim 50, wherein said amplitude modulation is performed such that a mean amplitude of said reference symbol substantially corresponds to a mean amplitude of the remaining multi-carrier modulated signal.

53. The method according to claim 47, wherein said bit sequence is a pseudo random bit sequence having good autocorrelation characteristics.

54. The method according to claim 47, wherein a number of useful symbols in each frame is defined depending on channel properties of a channel through which the signal or the multi-carrier modulated signal is transmitted.

55. A method for frame synchronization of a signal having a frame structure, each frame of said frame structure comprising at least one useful symbol, a guard interval associated with said at least one useful symbol and a reference symbol, said method comprising the steps of:
receiving said signal;
down-converting said received signal;
performing an amplitude-demodulation of said down-converted signal in order to generate an envelope;
correlating said envelope with a predetermined reference pattern in order to detect the signal reference pattern of said reference symbol in said signal; and
performing said frame synchronization based on the detection of said signal reference pattern.

56. The method according to claim 55, further comprising the step of performing a fast automatic gain control of said received down-converted signal prior to the step of performing said amplitude-demodulation.

57. The method according to claim 55, wherein the step of performing said amplitude-demodulation comprises the step of calculating an amplitude of said signal using the $alpha_{max+}$ $beta_{min-}$ method.

58. The method according to claim 55, further comprising the steps of sampling respective amplitudes of said received down-converted signal and comparing said sampled amplitudes with a predetermined threshold in order to generate a bit sequence in order to perform said amplitude demodulation.

59. The method according to claim 58, wherein the step of sampling respective amplitudes of said received down-converted signal further comprises the step of performing an over-sampling of said received down-converted signal.

60. The method according to claim 55, further comprising the step of applying a result of the frame synchronization for a frame in said signal to at least one subsequent frame in said signal.

61. A method for frame synchronization of a multi-carrier modulated signal having frame structure, each frame of said frame structure comprising at least one useful symbol, a guard interval associated to said at least one useful symbol and a reference symbol, said method comprising the steps of:

receiving said multi-carrier modulated signal;

down-converting said received multi-carrier modulated signal;

performing an amplitude-demodulation of said down-converted multi-carrier modulated signal in order to generate an envelope;

correlating said envelope with a predetermined reference pattern in order to detect the signal reference pattern of said reference symbol in said multi-carrier modulated signal;

performing said frame synchronization based on the detection of said signal reference pattern;

extracting said reference symbol and said at least one guard interval from said down-converted received multi-carrier modulated signal based on said frame synchronization;

performing a Fourier transform in order to provide a sequence of spectra from said at least one useful symbol;

de-mapping said sequence of spectra in order to provide a bitstream.

62. The method according to claim 61, further comprising the step of performing a fast automatic gain control of said received down-converted multi-carrier modulated signal prior to the step of performing said amplitude-demodulation.

63. The method according to claim 61, wherein the step of performing said amplitude-demodulation comprises the step of calculating an amplitude of said multi-carrier modulated signal using the $alpha_{max+}$ $beta_{min-}$ method.

64. The method according to claim 61, further comprising the steps of sampling respective amplitudes of said received down-converted multi-carrier modulated signal and comparing said sampled amplitudes with a predetermined threshold in order to generate a bit sequence in order to perform said amplitude demodulation.

65. The method according to claim 64, wherein the step of sampling respective amplitudes of said received down-converted multi-carrier modulated signal further comprises the step of performing an over-sampling of said received down-converted multi-carrier modulated signal.

66. The method according to claim 51, further comprising the step of applying a result of the frame synchronization for a frame in said signal to at least one subsequent frame in said multi-carrier modulated signal.

67. The method according to claim 55, further comprising the step of detecting a location of said signal reference pattern based on an occurrence of a maximum of a

correlation signal when correlating said envelope with said predetermined reference pattern.

68. The method according to claim 57, further comprising the steps of:
weighting a plurality of maxima of said correlation signal such that a maximum occurring first is weighted stronger than any subsequently occurring maximum; and
detecting said location of said signal reference pattern based on the greatest one of said weighted maxima.

69. The method according to claim 68, further comprising the step of:
disabling the step of performing said frame synchronization for a predetermined period of time after having switched-on a receiver performing said method for frame synchronization.

70. An apparatus for generating a signal having a frame structure, each frame of said frame structure comprising at least one useful symbol, a guard interval associated to said at least one useful symbol and a reference symbol, said apparatus comprising:
an amplitude modulator for performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of said reference symbol; and
means for inserting the amplitude modulated bit sequence into said signal as said reference symbol.

71. The apparatus according to claim 70, wherein said signal is an orthogonal frequency division multiplexed signal.

72. The apparatus according to claim 70, wherein a mean amplitude of said reference symbol substantially corresponds to a mean amplitude of the remaining signal.

73. An apparatus for generating a multi-carrier modulated signal having a frame structure, each frame of said frame structure comprising at least one useful symbol,

a guard interval associated to said at least one useful symbol and a reference symbol, said apparatus comprising:

means for providing a bitstream;

means for mapping bits of said bitstream to carriers in order to provide a sequence of spectra;

means for performing an inverse Fourier transform in order to provide multi-carrier modulated symbols;

means for associating a guard interval to each multi-carrier modulated symbol;

means for generating said reference symbol comprising an amplitude modulator for performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of said reference symbol;

means for associating said reference symbol to a predetermined number of multi-carrier modulated symbols and associated guard intervals in order to define said frame; and

means for inserting the amplitude modulated bit sequence into said signal as said reference symbol.

74. The apparatus according to claim 73, wherein said multi-carrier modulated signal is an orthogonal frequency division multiplex signal.

75. The apparatus according to claim 72, wherein said means for generating said reference symbol performs the amplitude modulation such that a mean amplitude of said reference symbol substantially corresponds to a mean amplitude of the remaining multi-carrier modulated signal.

76. The apparatus according to claim 70, wherein said means for generating said reference symbol generates a pseudo random bit sequence having good autocorrelation characteristics as said bit sequence.

77. The apparatus according to claim 70, comprising means for determining a number of useful symbols in each frame depending on channel properties of a channel through which the signal or the multi-carrier modulated signal is transmitted.

78. An apparatus for frame synchronization of a signal having a frame structure, each frame of said frame structure comprising at least one useful symbol, a guard interval associated to said at least one useful symbol and a reference symbol, said apparatus comprising:
receiving means for receiving said signal;
a down-converter for down-converting said received signal;
an amplitude-demodulator for performing an amplitude demodulation of said down-converted signal in order to generate an envelope;
a correlator for correlating said envelope with a predetermined reference pattern in order to detect the signal reference pattern of said reference symbol in said signal; and
means for performing said frame synchronization based on the detection of said signal reference pattern.

79. The apparatus according to claim 78, further comprising means for performing a fast automatic gain control of said received down-converted signal preceding said amplitude-demodulator.

80. The apparatus according to claim 78, wherein said amplitude-demodulator comprises means for calculating an amplitude of said signal using the $alpha_{max+}$ $beta_{min-}$ method.

81. The apparatus according to claim 78, further comprising means for sampling respective amplitudes of said received down-converted signal, wherein said amplitude-demodulator comprises means for comparing said sampled amplitudes with a predetermined threshold in order to generate a bit sequence.

82. The apparatus according to claim 81, wherein said means for sampling comprises means for over-sampling said received down-converted signal.

83. The apparatus according to claim 78, further comprising means for applying a result of the frame synchronization for a frame in said signal to at least one subsequent frame in said signal.

84. An apparatus for frame synchronization of a multi-carrier modulated signal having a frame structure, each frame of said frame structure comprising at least one useful symbol, a guard interval associated to said at least one useful symbol and a reference symbol, said apparatus comprising:
a receiver for receiving said multi-carrier modulated signal;
a down-converter for down-converting said received multi-carrier modulated signal;
an amplitude-demodulator for performing an amplitude-demodulation of said down-converted multi-carrier modulated signal in order to generate an envelope;
a correlator for correlating said envelope with a predetermined reference pattern in order to detect the signal reference pattern of said reference symbol in said multi-carrier modulated signal;
means for performing said frame synchronization based on the detection of said signal reference pattern;
means for extracting said reference symbol and said at least one guard interval from said down-converted received multi-carrier modulated signal based on said frame synchronization in order to generate said at least one useful symbol;
means for performing a Fourier transform in order to provide a sequence of spectra from said at least one useful symbol; and
means for de-mapping said sequence of spectra in order to provide a bitstream.

85. The apparatus according to claim 84, further comprising means for performing a fast automatic gain control of said received down-converted multi-carrier modulated signal preceding said amplitude-demodulator.

86. The apparatus according to claim 84, wherein said amplitude-demodulator comprises means for calculating an amplitude of said multi-carrier modulated signal using the $alpha_{max+}$ $beta_{min-}$ method.

87. The apparatus according to claim 84, further comprising means for sampling respective amplitudes of said received down-converted multi-carrier modulated signal, wherein said amplitude-demodulator comprises means for comparing said sampled amplitudes with a predetermined threshold in order to generate a bit sequence.

88. The apparatus according to claim 87, wherein said means for sampling comprises means for over-sampling said received down-converted multi-carrier modulated signal.

89. The apparatus according to claim 84, further comprising means for applying a result of the frame synchronization for a frame in said multi-carrier modulated signal to at least one subsequent frame in said multi-carrier modulated signal.

90. The apparatus according to claim 78, further comprising means for detecting a location of said signal reference pattern based on an occurrence of a maximum of a correlation signal output of said correlator.

91. The apparatus according to claim 90, further comprising means for weighting a plurality of maxima of said correlation signal such that a maximum occurring first is weighted stronger than any subsequently occurring maximum; and
means for detecting said location of said signal reference pattern based on the greatest one of said weighted maxima.

92. The apparatus according to claim 91, further comprising means for disabling said means for performing said frame synchronization for a predetermined period of time after having switched-on a receiver comprising said apparatus for frame synchronization.

REMARKS

By the present Preliminary Amendment, claims 1-48 annexed to the International Preliminary Examination Report dated February 9, 2000 are being cancelled and replaced with new claims 47-92. In the new claims, multiple dependencies and parenthetical reference numerals have been eliminated.

A substitute specification is being submitted to facilitate processing of this application. A marked-up copy of the substitute specification is also being provided to show the new changes which are beyond those previously made during the international stage. The substitute specification contains no new matter.

Early and favorable action on this application is respectfully requested. Should the Examiner have any questions, the Examiner is invited to contact the undersigned attorney at the local telephone number listed below.

Respectfully submitted,

John E. Holmes

John E. Holmes
Attorney for Applicant
Reg. No. 29,392

Roylance, Abrams, Berdo & Goodman
1300 19th Street, N.W., Suite 600
Washington, D.C. 20036-2680
(202) 659-9076

Dated: October 13, 2000

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FRAME STRUCTURE AND FRAME SYNCHRONIZATION FOR MULTICARRIER SYSTEMS

FIELD OF THE INVENTION

The present invention relates to methods and apparatus for generating a signal having a frame structure, wherein each frame of the frame structure is composed of useful symbols, a guard interval associated to each useful symbol and one reference symbol. In addition, the present invention relates to methods and apparatus for frame synchronization of signals having the above structure.

The present invention is particularly useful in a MCM transmission system (MCM = Multi-carrier modulation) using an orthogonal frequency division multiplexing (OFDM) for digital broadcasting.

BACKGROUND OF THE INVENTION

In a MCM (OFDM) transmission system the binary information is represented in the form of a complex spectrum, i.e. a distinct number of complex subcarrier symbols in the frequency domain. In the modulator a bitstream is represented by a sequence of spectra. Using an inverse Fourier-transform (IFFT) a MCM time domain signal is produced from this sequence of spectra.

In case of a transmission of this described MCM signal via a multipath channel with memory, intersymbol interference (ISI) occurs due to multipath dispersion. To avoid ISI a guard interval of fixed length is added between adjacent MCM symbols in time. The guard interval is chosen as cyclic prefix. This means that the last part of a time domain MCM symbol is placed in front of the symbol to get a periodic extension. If the fixed length of the chosen guard interval is

greater than the maximum multipath delay, ISI will not occur.

In the receiver the information which is in the frequency and time domain (MCM) has to be recovered from the MCM time domain signal. This is performed in two steps. Firstly, optimally locating the FFT window, thus eliminating the guard interval in front of each MCM time domain symbol. Secondly, performing a Fourier Transform of the sequence of useful time samples thus obtained.

As a result a sequence of spectral symbols is thus recovered. Each of the symbols contains a distinct number of information carrying subcarrier symbols. Out of these, the information bits are recovered using the inverse process of the modulator.

Performing the above described method, the following problem occurs in the receiver. The exact position of the guard interval and hence the position of the original useful parts of the time domain MCM symbols is generally unknown. Extraction of the guard interval and the subsequent FFT-transform of the resulting useful part of the time signal is not possible without additional information. To provide this additional information, a known (single carrier) sequence in the form of a (time domain) reference symbol is inserted into the time signal. With the knowledge about the positions of the reference symbols in the received signal, the exact positions of the guard intervals and thus the interesting information carrying time samples are known.

The periodical insertion of the reference symbol results in a frame structure of the MCM signal. This frame structure of a MCM signal is shown in Figure 1. One frame of the MCM signal is composed of a plurality of MCM symbols 10. Each MCM symbol 10 is formed by an useful symbol 12 and a guard interval 14 associated therewith. As shown in Figure 1, each frame comprises one reference symbol 16.

A functioning synchronization in the receiver, i.e. frame, frequency, phase, guard interval synchronization is necessary for the subsequent MCM demodulation. Consequently, the first and most important task of the base band processing in the receiver is to find and synchronize to the reference symbol.

DESCRIPTION OF THE PRIOR ART

Most prior art methods for frame synchronization have been developed for single carrier transmission over the AWGN channel (AWGN = Additive White Gaussian Noise). These prior art methods based on correlation are, without major changes, not applicable for transmission over multipath fading channels with large frequency offsets or MCM transmission systems that use, for example, an orthogonal frequency division multiplexing.

For MCM transmission systems particular frame synchronization methods have been developed.

Warner, W.D., Leung C.: OFDM/FM Frame Synchronization for Mobile Radio Data Communication, IEEE Trans. On Vehicular Technology, vol. VT-42, August 1993, pp. 302 to 313, teaches the insertion of reference symbols in the form of tones in parallel with the data into the MCM symbol. The reference symbols occupy several carriers of the MCM signal. In the receiver, the synchronization carriers are extracted in the frequency domain, after a FFT transform (FFT = fast Fourier transform) using a correlation detector. In the presence of large frequency offsets, this algorithm becomes very complex because several correlators must be implemented in parallel.

A further prior art technique is to insert a periodic reference symbol into the modulated MCM signal. This reference symbol is a CAZAC sequence (CAZAC = Constant Amplitude Zero Autocorrelation). Such techniques are taught by: Classen, F., Meyr, H.: Synchronization algorithms for an OFDM system

Vehic. Technology Conference, 1997; Schmidl, T.M., Cox, D.C.: Low-Overhead, Low-Complexity [Burst] Synchronization for OFDM Transmission, *Proc. IEEE Int. Conf. on Commun.*, 1996. In such systems, the receiver's processor looks for a periodic repetition. For these algorithms coarse frequency synchronization has to be achieved prior to or at least simultaneously with frame synchronization.

Van de Beek, J, Sandell, M., Isaksson, M, Börjesson, P.: Low-Complex Frame Synchronization in OFDM Systems, *Proc. of the ICUPC*, 1995, avoid the insertion of additional reference symbols or pilot carriers and use instead the periodicity in the MCM signal which is inherent in the guard interval and the associated cyclical extension. This method is suitable only for slowly varying fading channels and small frequency offsets.

US-A-5,191,576 relates to a method for the diffusion of digital data designed to be received notably by mobile receivers moving in an urban environment. In this method, the header of each frame of a broadcast signal having a frame structure has a first empty synchronization symbol and a second unmodulated wobbled signal forming a two-stage analog synchronization system. The recovery of the synchronization signal is achieved in an analog way, without prior extraction of a clock signal at the binary level.

EP 0631406 A relates to data signals, COFDM signals, for example, and to methods and apparatus for diffusing said signals. The COFDM signals comprises a sequence of symbols, each symbol having an useful portion and a guard interval. Two symbols of a COFDM signal are provided as synchronization symbols. One of the two symbols is a zero symbol, whereas the other thereof is a synchronization symbol which is formed by an unmodulated multiplex of the carrier frequencies having a constant envelope. Beside the two symbols as synchronization symbols, it is taught in EP 0631406 A to modulate the pilot frequency of the data signal with a reference signal which carries the synchronization information. This reference signal modulated on the pilot frequency of the data signal can be used

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by a MABLR demodulator.

WO 98/00946 A relates to a system for a timing and frequency synchronization of OFDM signals. Two OFDM training symbols are used to obtain full synchronization in less than two data frames. The OFDM training symbols are placed into the OFDM signal, preferably at least once every frame. The first OFDM training symbol is produced by modulating the even-numbered OFDM sub-carriers whereas the odd-numbered OFDM sub-carriers are suppressed. Thus, in accordance with WO 98/00946 A, the first OFDM training symbol is produced by modulating the even-numbered carriers of this symbol with a first predetermined PN sequence.

Moose: "A technique for orthogonal frequency division multiplexing frequency offset correction", IEEE TRANSACTIONS ON COMMUNICATIONS, Vo. 42, No. 10, October 1994, pages 2908 to 2914, teaches methods for correcting frequency offsets in OFDM digital communications. The methods involve repetition of a data symbol and comparison of the phases of each of the carriers between the successive symbols. The phase shift of each of the carriers between the repeated symbols is due to the frequency offset since the modulation phase values are not changed in the repeated symbols.

Keller; Hanzo: "Orthogonal frequency division multiplex synchronization techniques for wireless local area networks", IEEE INTERNATIONAL SYMPOSIUM ON PERSONAL, INDOOR AND MOBILE RADIO COMMUNICATIONS, October 15, 1996, pages 963 to 967, teach frequency acquisition, frequency tracking, symbol synchronization and frame synchronization techniques. Regarding the frame synchronization, it is taught to use a reference symbol which consists of repetitive copies of a synchronization pattern of pseudo-random samples. The frame synchronization is achieved by autocorrelation techniques using the periodic synchronization segments such that for the synchronization algorithms proposed no a priori knowledge of the synchronization sequences is required.

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The methods for frame synchronization available up to date require either prior achieved frequency synchronization or become very complex when the signal in the receiver is corrupted by a large frequency offset.

If there is a frequency offset in the receiver, as can easily be the case when a receiver is powered-on and the frequency synchronization loop is not yet locked, problems will occur. When performing a simple correlation there will only be noise at the output of the correlator , i.e. no maximum can be found if the frequency offset exceeds a certain bound. The size of the frequency offset depends on the length (time) of the correlation to be performed, i.e. the longer it takes, the smaller the allowed frequency offset becomes. In general, frequency offset increases implementation complexity.

Frequency offsets occur after power-on or later due to frequency deviation of the oscillators used for down-conversion to baseband. Typical accuracies for the frequency of a free running local oscillator (LO) are at ±50 ppm of the carrier frequency. With a carrier frequency in S-band (e.g. 2.34 GHz) there will be a maximum LO frequency deviation of above 100 kHz (117.25 kHz). A deviation of this magnitude puts high demands on the above methods.

In the case of multipath impaired transmission channel, a correlation method yields several correlation maxima in addition to the distinct maximum for an AWGN channel. The best possible frame header position, i.e. the reference symbol, has to be selected to cope with this number of maxima. In multipath channels, frame synchronization methods with correlations can not be used without major changes. Moreover, it is not possible to use data demodulated from the MCM system, because the demodulation is based on the knowledge of the position of the guard interval and the useful part of the MCM symbol.

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SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method and an apparatus for generating a signal having a frame structure that allow a frame synchronization after the signals have been transmitted even in the case of a carrier frequency offset or in the case of a transmission via a multipath fading channel.

It is a further object of the present invention to provide a method and an apparatus for frame synchronization of a signal having a frame structure even in the case of a carrier frequency offset.

In accordance with a first aspect, the present invention provides a method for generating a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the method comprising the steps of performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the reference symbol and inserting the amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a second aspect, the present invention provides a method for generating a multi-carrier modulated signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the method comprising the steps of:

providing a bitstream;

mapping bits of the bitstream to carriers in order to provide a sequence of spectra;

performing an inverse Fourier transform in order to provide multi-carrier modulated symbols;

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associating a guard interval to each multi-carrier modulated symbol;

generating the reference symbol by performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the reference symbol;

associating the reference symbol to a predetermined number of multi-carrier modulated symbols and associated guard intervals in order to define the frame; and

inserting said amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a third aspect, the present invention provides a method for frame synchronization of a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated with the at least one useful symbol and a reference symbol, the method comprising the steps of:

receiving the signal;

down-converting the received signal;

performing an amplitude-demodulation of the down-converted signal in order to generate an envelope;

correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the signal; and

performing the frame synchronization based on the detection of the signal reference pattern.

In accordance with a fourth aspect, the present invention provides a method for frame synchronization of a multi-carrier

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modulated signal having frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the method comprising the steps of:

receiving the multi-carrier modulated signal;

down-converting the received multi-carrier modulated signal;

performing an amplitude-demodulation of the down-converted multi-carrier modulated signal in order to generate an envelope;

correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the multi-carrier modulated signal;

performing the frame synchronization based on the detection of the signal reference pattern;

extracting the reference symbol and the at least one guard interval from the down-converted received multi-carrier modulated signal based on the frame synchronization;

performing a Fourier transform in order to provide a sequence of spectra from the at least one useful symbol;

de-mapping the sequence of spectra in order to provide a bitstream.

In accordance with a fifth aspect, the present invention provides an apparatus for generating a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising an amplitude modulator for performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the

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reference symbol; and

means for inserting the amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a sixth aspect, the present invention provides an apparatus for generating a multi-carrier modulated signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising:

means for providing a bitstream;

means for mapping bits of the bitstream to carriers in order to provide a sequence of spectra;

means for performing an inverse Fourier transform in order to provide multi-carrier modulated symbols;

means for associating a guard interval to each multi-carrier modulated symbol;

means for generating the reference symbol by an amplitude modulator for performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the reference symbol;

means for associating the reference symbol to a predetermined number of multi-carrier modulated symbols and associated guard intervals in order to define the frame; and

means for inserting the amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a seventh aspect, the present invention provides an apparatus for frame synchronization of a signal

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having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising:

receiving means for receiving the signal;

a down-converter for down-converting the received signal;

an amplitude-demodulator for performing an amplitude demodulation of the down-converted signal in order to generate an envelope;

a correlator for correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the signal; and

means for performing the frame synchronization based on the detection of the signal reference pattern.

In accordance with a eighth aspect, the present invention provides an apparatus for frame synchronization of a multi-carrier modulated signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising:

a receiver for receiving the multi-carrier modulated signal;

a down-converter for down-converting the received multi-carrier modulated signal;

an amplitude-demodulator for performing an amplitude-demodulation of the down-converted multi-carrier modulated signal in order to generate an envelope;

a correlator for correlating the envelope with a

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predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the multi-carrier modulated signal;

means for performing the frame synchronization based on the detection of the signal reference pattern;

means for extracting the reference symbol and the at least one guard interval from the down-converted received multi-carrier modulated signal based on the frame synchronization in order to generate the at least one useful symbol;

means for performing a Fourier transform in order to provide a sequence of spectra from the at least one useful symbol; and

means for de-mapping the sequence of spectra in order to provide a bitstream.

The present invention provides a novel structure of the reference symbol along with a method to determine the position of the reference symbol and thus the start of a frame in a signal having a frame structure as shown for example in Figure 1.

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of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the reference symbol;

means for associating the reference symbol to a predetermined number of multi-carrier modulated symbols and associated guard intervals in order to define the frame; and

means for inserting the amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a seventh aspect, the present invention provides an apparatus for frame synchronization of a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising:

receiving means for receiving the signal;

a down-converter for down-converting the received signal;

an amplitude-demodulator for performing an amplitude demodulation of the down-converted signal in order to generate an envelope;

a correlator for correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the signal; and

means for performing the frame synchronization based on the detection of the signal reference pattern.

In accordance with an eighth aspect, the present invention provides an apparatus for frame synchronization of a multi-carrier modulated signal having a frame structure, each

frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising:

a receiver for receiving the multi-carrier modulated signal;

a down-converter for down-converting the received multi-carrier modulated signal;

an amplitude-demodulator for performing an amplitude-demodulation of the down-converted multi-carrier modulated signal in order to generate an envelope;

a correlator for correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the multi-carrier modulated signal;

means for performing the frame synchronization based on the detection of the signal reference pattern;

means for extracting the reference symbol and the at least one guard interval from the down-converted received multi-carrier modulated signal based on the frame synchronization in order to generate the at least one useful symbol;

means for performing a Fourier transform in order to provide a sequence of spectra from the at least one useful symbol; and

means for de-mapping the sequence of spectra in order to provide a bitstream.

The present invention provides a novel structure of the reference symbol along with a method to determine the position of the reference symbol and thus the start of a frame in a

signal having a frame structure as shown for example in Figure 1.

The invention relates to a method for finding frame headers independently of other synchronization information and thus for positioning the FFT windows correctly. This includes the extraction of a guard interval. The method is based on the detection of a known reference symbol of the frame header in the reception signal, e.g. in the digital complex baseband. The new frame synchronization will be performed as the first synchronization task.

Synchronization to the reference symbol, i.e. the frame header is the first step to initiate radio reception. The reference symbol is structured to accomplish this. The information contained in the reference symbol must therefore be independent of other synchronization parameters, e.g. frequency offset. For this reason, in accordance with the present invention, the form of the reference symbol selected is an amplitude modulated sequence (AM sequence) in the complex baseband. Thus, the information contained in the reference symbol is only that given in the amplitude and not that in the phase. Note that the phase information will be corrupted by a possible frequency offset. In preferred embodiments of the present invention, the AM information is constructed from a bit sequence with special features. The information sequence is selected in a way which makes it easy and secure to find it in the time domain. A bit sequence with good autocorrelation properties is chosen. Good autocorrelation properties means a distinct correlation maximum in a correlation signal which should be as white as possible.

A pseudo random bit sequence (PRBS) having good autocorrelation properties meets the above requirements.

Using the envelope of the signal to carry bit information offers additional flexibility. First it has to be decided which envelope values should correspond to the binary values

of 0 and 1. The parameters are mean amplitude and modulation rate. Attention should be paid to selecting the mean amplitude of the reference symbol (performance) identically to the mean amplitude of the rest of the frame. This is due to the amplitude normalization (AGC; AGC = Automatic Gain Control) performed in the receiver. It is also possible to select the mean amplitude of the reference symbol higher than the mean signal amplitude, but then care has to be taken that the time constant of the AGC (1/sensitivity) is selected high enough to secure that the strong (boosted) signal of the reference symbol does not influence the AGC control signal and thus attenuate the signal following the reference symbol.

Another degree of freedom can be characterized as modulation degree d. This parameter is responsible for the information density of the modulating signal mod(t) formed out of the binary sequence bin(t) as follows: mod(t) = bin(t/d). This modulation degree can be chosen as free parameter fixed by an integer or real relation to the sampling rate. It is appropriate to choose the modulation degree d as an integer value because of the discrete values of the binary sequence:

d = 1:	mod(m)	= bin(m)	
d = 2:	mod(m)	= bin(m/2)	for m even
		= bin_int(m/2)	for m odd
d = 3:	mod(m)	= bin(m/3)	for m = 0, ±3, ±6, ±9,
		bin_int(m/3)	else

The signal values bin_int(m/d) are computed from the binary sequence bin(m) by ideal interpolation (between the discrete integer values m) with the factor of d. This is similar to an ideal sampling rate expansion (with sin(x)/x interpolation), but the sampling rate remains, only less bits of the binary sequence bin(m) correspond to the resulting interpolated sequence mod(m). This parameter m indicates the discrete time.

With increasing m the modulating signal mod(t) is expanded in time relative to the basic binary sequence, this results in a bandwidth compression of the resulting AM spectrum with regard to the basic binary sequence. A time expansion by a factor 2 results in a bandwidth compression by the same factor 2. In addition to the bandwidth compression, a further advantage of a higher modulation degree d is a reduced complexity of the search method in the receiver due to the fact that only each dth sample has a corresponding binary value. Choosing the factor d = 1 is not preferred since this would result in aliasing due to disregard of the sampling theorem. For this reason, in a preferred embodiment of the present invention d is chosen to be 2.

The choice of length and repetition rate of the reference symbol is, on the one hand, dominated by the channel properties, e.g. the channel's coherence time. On the other hand the choice depends on the receiver requirements concerning mean time for initial synchronization and mean time for re-synchronization after synchronization loss due to a channel fade.

In the receiver, the first step after the down-conversion of the received signal is to perform an amplitude-demodulation of the down-converted signal in order to generate an envelope, i.e. in order to determine the amplitude of the signal. This envelope is correlated with a replica reference pattern in order to detect the signal reference pattern of the reference symbol in the signal. In the case of a AWGN channel, the result of this correlation will be a white noise signal with zero mean value and with a clearly visible (positive) maximum. In the case of a multipath channel, several maxima will occur in the correlation signal computed by this correlation. In the former case, the location of the reference symbol is determined based on the signal maximum, whereas in the latter case a weighting procedure is performed in order to find out the maximum corresponding to the location of the reference symbol.

Thus, the present invention shows how to find a reference symbol by a detection method which is simple. Furthermore, the present invention can be used for one-carrier or multi-carrier systems. The present invention is particularly useful in multi-carrier modulation systems using an orthogonal frequency division multiplexing, for example in the field of digital broadcasting. The synchronization methods according to the present invention are independent of other synchronization steps. Since the information needed for the synchronization is contained in the envelope of the preamble, i.e. the reference symbol, the reference symbol is independent of possible frequency offsets. Thus, a derivation of the correct down sampling timing and the correct positioning of the FFT window can be achieved. The reference symbol of the present invention can be detected even if the frequency synchronization loop is not yet locked or even in the case of a carrier frequency offset. The frame synchronization method in accordance with the present invention is preferably performed prior to other and without knowledge of other synchronization efforts.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following, preferred embodiments of the present invention will be explained in detail on the basis of the drawings enclosed, in which:

Figure 1 shows a schematic view of a signal having a frame structure;

Figure 2 shows a block diagram of a MCM system to which the present invention can be applied;

Figure 3 shows a schematic block diagram of a frame and frequency synchronization system in a MCM receiver;

Figure 4 shows a schematic diagram of an apparatus for frame synchronization; and

Figure 5 shows a typical channel impulse response of a single frequency network in S-band.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Although the present invention is explained mainly referring to a MCM system, it is obvious that the present invention can be used in connection with different signal transmissions that are based on different kinds of modulation.

Figure 2 shows a MCM system overview on the basis of which the present invention will be described in detail. At 100 a MCM transmitter is shown that substantially corresponds to a prior art MCM transmitter except for the kind of the reference symbol being added to each frame of a MCM signal. A description of such a MCM transmitter can be found, for example, in William Y. Zou, Yiyan Wu, "COFDM: AN OVERVIEW", IEEE Transactions on Broadcasting, vol. 41, No. 1, March 1995.

A data source 102 provides a serial bitstream 104 to the MCM transmitter. The incoming serial bitstream 104 is applied to a bit-carrier mapper 106 which produces a sequence of spectra 108 from the incoming serial bitstream 104. An inverse fast Fourier transform (FFT) 110 is performed on the sequence of spectra 108 in order to produce a MCM time domain signal 112. The MCM time domain signal forms the useful MCM symbol of the MCM time signal. To avoid intersymbol interference (ISI) caused by multipath distortion, a unit 114 is provided for inserting a guard interval of fixed length between adjacent MCM symbols in time. In accordance with a preferred embodiment of the present invention, the last part of the useful MCM symbol is used as the guard interval by placing same in front of the useful symbol. The resulting MCM symbol is shown at 115 in Figure 2 and corresponds to the MCM symbol 10 depicted in Figure 1.

signal transmitted through the channel 122 is received at the receiver front end 132. The down-converted MCM signal is sampled at the receiver front end 132 and is, in the preferred embodiment, provided to a fast running automatic gain control (time constant < MCM symbol duration) in order to eliminate fast channel fluctuations (channel coherence time ≈ MCM symbol duration). The fast AGC 162 is used in addition to the normally slow AGC in the signal path, in the case of transmission over a multipath channel with long channel impulse response and frequency selective fading. The fast AGC adjusts the average amplitude range of the signal to the known average amplitude of the reference symbol. The so processed symbol is provided to an amplitude determining unit 164.

The amplitude determining unit 164 can use the simple $alpha_{max+}$ $beta_{min-}$ method in order to calculate the amplitude of the signal. This method is described for example in Palachels A.: DSP-mP Routine Computes Magnitude, EDN, October 26, 1989; and Adams, W. T., and Bradley, J.: Magnitude Approximations for Microprocessor Implementation, IEEE Micro, Vol. 3, No. 5, October 1983.

The output signal of the amplitude determining unit 164 is applied to a correlator 166. In the correlator 166, a cross correlation between the amplitude signal output from the amplitude determining unit 164 and a known ideal amplitude information is computed. The known ideal amplitude information is stored in the correlator. For both, the amplitude and the known ideal amplitude information, their amplitudes are symmetrically to zero relative to their average amplitude.

In the ideal AWGN case, the result will be a white noise signal with zero mean value and with a clearly visible positive maximum. In this ideal AWGN case, the position of the single maximum is evaluated in a maximum position unit 172. On the basis of this evaluation, the reference symbol and the guard intervals are extracted from the MCM signal in a combined reference symbol/guard extraction unit 136/138. Although these units are shown as a combined unit 136/138 in Figure 4, it is

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clear that separate units can be provided. The MCM signal is transmitted from the RF front end 150 to the reference symbol/guard extraction unit 136/138 via a low pass filter 174.

In the case of time spreading encountered in a multipath channel, several maxima corresponding to the number of clusters in the channel impulse response occur in the output signal of the correlator. A schematic view of three such clusters located in a time window of maximum about 60 microseconds is shown in Figure 5. Out of the several maxima caused by the time spreading encountered in a multipath channel, the best one has to be selected as the position of the frame header, i.e. the reference symbol. Therefore, a threshold unit 168 and a weighting unit 170 are provided between the correlator 166 and the maximum position unit 172. The threshold unit 168 is provided to remove maxima having an amplitude below a predetermined threshold. The weighting unit 164 is provided in order to perform a weighting procedure on the remaining maxima such that the maximum corresponding to the reference symbol can be determined. An examplary weighting procedure performed in the weighting unit 170 is as follows.

The first significant maximum is considered to be the best one. The output signal of the correlator is observed from the first detected maximum onwards for the maximum length of the channel impulse response and an amplitude weighting function is applied to the signal. Because the actual channel impulse response length is unknown, the following fact can be remembered. During system design, the length of the channel impulse response has to be investigated. In a MCM system, the guard interval shall be equal or longer than the maximum expected channel impulse response. For this reason, the part (interval with l_I samples, l_I corresponding to the maximum expected channel impulse response, i.e. the guard interval length) of the correlation output signal starting with the first maximum,

$$I_{k0}(n) = r(k_0 + n),\ 0 \le n \le l_I - 1 \qquad \text{(Eq.1)}$$

with k_0 being the position of the first maximum, will be examined to find the best frame start position. The above

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signal part is weighted with the function

$$W(n) = 10^{-\frac{weight\_dB}{10} \frac{n}{l_I - 1}} \qquad \text{(Eq.2)}$$

The position (n_{max}) of the maximum in the resulting signal interval

$$I_{k0,weighted}(n) = [r(k_0+n)\ W(n)] = [r(k_0+n)\ 10^{-\frac{weight\_dB}{10} \frac{n}{l_I - 1}}]$$

$$0 \le n \le l_I - 1 \qquad \text{(Eq.3)}$$

will be chosen as best frame start position.

r(k) designates the output signal of the correlator (166) at the time k. The signal is present with a clock frequency which is determined by the multiplication: oversampling factor * subcarrier symbol frequency. The parameter k designates the discrete time in sample clocks. This signal is windowed with information from the threshold unit 168. An interval having the length of l_I values is extracted from the signal r(k). The first value being written into the interval is the correlation start value at the time k_0, at which the output value $r(k_0)$ exceeds the threshold value of the threshold unit 168 for the first time. The interval with the windowed signal is designated by the term $I(k_0)$. The parameter n designates the relative time, i.e. position, of a value inside the interval.

Using the described weighting operation, the earlier correlation maxima are more likely to be chosen as right frame start position. A later coming maximum will only be chosen as frame start position, if the value of the maximum is significantly higher than the earlier one. This operation is applicable especially for MCM, because here it is better to detect the frame start positions some samples too early than some samples too late. Positioning the frame start some samples too early leads to positioning the FFT window a little bit into the guard interval, this contains information of the same MCM symbol and therefore leads to little effects. If the frame start position is detected some samples too late, then the FFT window includes some samples of the following guard interval.

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This leads to a more visible degradation, because the following guard interval contains information of the following MCM symbol (ISI occurs).

It is important to know that the first visible correlation maximum after receiver power-on does not necessarily correspond to the first CIR (channel impulse response) cluster. It is possible that it is corresponding to a later cluster, see Figure 5. For this reason during power-on one should wait for a second frame start before starting demodulation.

It is clear that amplitude determining methods different from the described $alpha_{max+}$ $beta_{min-}$ method can be used. For simplification, it is possible to reduce the amplitude calculation to a detection as to whether the current amplitude is above or below the average amplitude. The output signal then consists of a -1/+1 sequence which will be correlated with a known bit sequence, also in -1/+1 values. This correlation can easily be performed using a simple integrated circuit (IC).

In addition, an oversampling of the signal received at the RF front end can be performed. For example, the received signal can be expressed with two times oversampling.

This oversampled signal is passed to a fast running AGC to eliminate fast channel fluctuations before the amplitude of the signal is calculated. The amplitude information will be hard quantized. Values larger than the mean amplitude, mean amplitude is 1, will be expressed as +1, values smaller than the mean amplitude will be expressed as -1. This -1/+1 signal is passed to the correlator that performs a cross correlation between the quantized signal and the stored ideal amplitude values of the reference symbol:

amp_sto(k) = 2*bin(k/4),
    if k = 2(oversampling factor) * 2(interpolation factor) *
   1,2,3...92
    (92 for 184 reference symbol and interpolation factor 2)
amp_sto(k) = 0, else, k <= 2(oversampling factor) *

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plary weighting procedure performed in the weighting unit 170 is as follows.

The first significant maximum is considered to be the best one. The output signal of the correlator is observed from the first detected maximum onwards for the maximum length of the channel impulse response and an amplitude weighting function is applied to the signal. Because the actual channel impulse response length is unknown, the following fact can be remembered. During system design, the length of the channel impulse response has to be investigated. In a MCM system, the guard interval shall be equal or longer than the maximum expected channel impulse response. For this reason, the part (interval with lI samples, lI corresponding to the maximum expected channel impulse response, i.e. the guard interval length) of the correlation output signal starting with the first maximum,

$$I_{k0}(n) = r(k_0+n),\ 0 \# n \# l_I - 1 \qquad \text{(Eq.1)}$$

with k_0 being the position of the first maximum, will be examined to find the best frame start position. The above signal part is weighted with the function

$$W(n) = 10^{-\frac{weight\_dB}{10}\frac{n}{l_I-1}} \qquad \text{(Eq.2)}$$

The position (n_{max}) of the maximum in the resulting signal interval

$$I_{k0,weighted}(n) = [r(k_0+n)\ W(n)] = [r(k_0+n)\ 10^{-\frac{weight\_dB}{10}\frac{n}{l_I-1}}]$$

$$0 \# n \# l_I - 1 \qquad \text{(Eq.3)}$$

will be chosen as best frame start position.

r(k) designates the output signal of the correlator (166) at the time k. The signal is present with a clock frequency which is determined by the multiplication: oversampling fac-

tor * subcarrier symbol frequency. The parameter k designates the discrete time in sample clocks. This signal is windowed with information from the threshold unit 168. An interval having the length of l_I values is extracted from the signal r(k). The first value being written into the interval is the correlation start value at the time k_0, at which the output value $r(k_0)$ exceeds the threshold value of the threshold unit 168 for the first time. The interval with the windowed signal is designated by the term $I(k_0)$. The parameter n designates the relative time, i.e. position, of a value inside the interval.

Using the described weighting operation, the earlier correlation maxima are more likely to be chosen as right frame start position. A later coming maximum will only be chosen as frame start position, if the value of the maximum is significantly higher than the earlier one. This operation is applicable especially for MCM, because here it is better to detect the frame start positions some samples too early than some samples too late. Positioning the frame start some samples too early leads to positioning the FFT window a little bit into the guard interval, this contains information of the same MCM symbol and therefore leads to little effects. If the frame start position is detected some samples too late, then the FFT window includes some samples of the following guard interval. This leads to a more visible degradation, because the following guard interval contains information of the following MCM symbol (ISI occurs).

It is important to know that the first visible correlation maximum after receiver power-on does not necessarily correspond to the first CIR (channel impulse response) cluster. It is possible that it is corresponding to a later cluster, see Figure 5. For this reason during power-on one should wait for a second frame start before starting demodulation.

It is clear that amplitude determining methods different from the described $alpha_{max+}$ $beta_{min-}$ method can be used. For simplification, it is possible to reduce the amplitude cal-

culation to a detection as to whether the current amplitude is above or below the average amplitude. The output signal then consists of a -1/+1 sequence which will be correlated with a known bit sequence, also in -1/+1 values. This correlation can easily be performed using a simple integrated circuit (IC).

In addition, an oversampling of the signal received at the RF front end can be performed. For example, the received signal can be expressed with two times oversampling.

This oversampled signal is passed to a fast running AGC to eliminate fast channel fluctuations before the amplitude of the signal is calculated. The amplitude information will be hard quantized. Values larger than the mean amplitude, mean amplitude is 1, will be expressed as +1, values smaller than the mean amplitude will be expressed as -1. This -1/+1 signal is passed to the correlator that performs a cross correlation between the quantized signal and the stored ideal amplitude values of the reference symbol:

```
amp_sto(k) = 2*bin(k/4),
   if k = 2(oversampling factor) * 2(interpolation factor) *
   1,2,3...92
   (92 for 184 reference symbol and interpolation factor 2)
amp_sto(k) = 0, else, k <= 2(oversampling factor)
   *2(interpolation factor) * 92
   (first part of amp_sto = [0 0 0 -1 0 0 0 1 0 0 0 1 0 0 0
   -1      0 .....  ]).
```

With this algorithm a correlation maximum of 92 is achievable.

Again, the maxima in the correlator output signal correspond to different frame start positions due to different multipath clusters. In this signal with various maxima the best frame start position has to be chosen. This is done in the following steps: The output of the correlator is given to a threshold detection. If the signal first time exceeds the

threshold (a threshold of 50 has proved to be applicable) the best position search algorithm is initialized. The correlator output signal in the interval following the threshold exceeding value will be weighted with the weighting function, see above. The position of the resulting maximum in the weighted signal will be chosen as best frame start position. With the knowledge about the best frame start position the guard interval extraction and the following MCM demodulation will be performed.

Some more efforts can be carried out to increase frame synchronization accuracy. These methods will be explained in the following.

A postprocessing of the frame start decision is performed in order a) to increase the reliability of the frame synchronization; b) to secure that no frame start position is disregarded; and c) to optimize the frame start position in case of varying CIR cluster positions.

Using information of other frame start positions. It is known that in front of each frame a reference symbol is inserted into the signal. If the position of the currently detected frame start has changed significantly regarding the last detected frame start, demodulation of the two frames in total and completely independent from each other is possible. It is also possible to buffer the last signal frame and to perform the required shift of the frame start position step by step with the MCM symbols of the frame. This results in an interpolative positioning of the single MCM symbols including simultaneous asynchronous guard interval extraction for the different MCM symbols.

Such an interpolative positioning of the FFT window is also possible if one frame start position is missing, i. e. the frame start has not been detected. If one frame start position is missing the guard interval extraction can be performed the same way as in the frame before without large performance degradation. This is due to the normally only

slowly varying CIR cluster positions, but only if the signal strength is good enough. Stopping demodulation and waiting for the next detected frame start position is also imaginable but not desirable because of the long interrupt.

What follows is an example of a reference symbol of 184 samples (subcarrier symbols) as provided by the inventive apparatus for generating a signal having a frame structure.

The underlying binary sequence of length 92 is:

```
bin = [0 1 1 0 1 1 0 1 0 1 1 0 1 0 1 0
       0 0 1 1 1 0 0 0 0 0 0 0 0 1 1 0
       1 1 1 1 1 0 0 0 1 1 1 0 0 0 0 0
       0 0 1 1 1 0 1 1 1 0 0 1 1 0 1 1
       1 0 1 1 0 1 0 1 0 1 1 0 1 1 0 1
       1 0 1 0 0 0 0 1 0 1 1 0]
```

The modulated binary sequence is:

```
i_q = [0.5 1.5 1.5 0.5 1.5 1.5 0.5 1.5 0.5 1.5 1.5 0.5 1.5
       0.5 1.5 0.5 0.5 0.5 1.5 1.5 1.5 0.5 0.5 0.5 0.5 0.5
       0.5 0.5 0.5 1.5 1.5 0.5 1.5 1.5 1.5 1.5 1.5 0.5 0.5
       0.5 1.5 1.5 1.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 1.5 1.5
       1.5 0.5 1.5 1.5 1.5 0.5 0.5 1.5 1.5 0.5 1.5 1.5 1.5
       0.5 1.5 1.5 0.5 1.5 0.5 1.5 0.5 1.5 1.5 0.5 1.5 1.5
       0.5 1.5 0.5 1.5 0.5 0.5 0.5 0.5 1.5 0.5 1.5 1.5 0.5]
```

This modulated binary sequence i_q is interpolated in order to produce an interpolated sequence i_q_int:

```
i_q_int = [0.5000 1.0635 1.5000 1.7195 1.5000 0.8706 0.5000
           0.8571 1.5000 1.7917 1.5000 0.8108 0.5000 1.0392
           1.5000 1.0392 0.5000 0.8108 1.5000 1.7984 1.5000
           0.8108 0.5000 1.0460 1.5000 0.9997 0.5000 0.9603
           1.5000 1.1424 0.5000 0.3831 0.5000 0.4293 0.5000
           0.9997 1.5000 1.5769 1.5000 1.5769 1.5000 1.0065
           0.5000 0.3899 0.5000 0.5325 0.5000 0.4931 0.5000
           0.4999 0.5000 0.4931 0.5000 0.5325 0.5000 0.3967
```

```
0.5000 0.9603 1.5000 1.7522 1.5000 0.8571 0.5000
0.8965 1.5000 1.6422 1.5000 1.4669 1.5000 1.4737
1.5000 1.6096 1.5000 0.9929 0.5000 0.4226 0.5000
0.4226 0.5000 0.9997 1.5000 1.5769 1.5000 1.5769
1.5000 1.0065 0.5000 0.3899 0.5000 0.5325 0.5000
0.4931 0.5000 0.4931 0.5000 0.5325 0.5000 0.3899
0.5000 1.0065 1.5000 1.5701 1.5000 1.6096 1.5000
0.8965 0.5000 0.8965 1.5000 1.6096 1.5000 1.5633
1.5000 1.0392 0.5000 0.2867 0.5000 0.9929 1.5000
1.7454 1.5000 0.8571 0.5000 0.9033 1.5000 1.6028
1.5000 1.6028 1.5000 0.9033 0.5000 0.8503 1.5000
1.7917 1.5000 0.8108 0.5000 1.0460 1.5000 0.9929
0.5000 0.9929 1.5000 1.0460 0.5000 0.8108 1.5000
1.7917 1.5000 0.8571 0.5000 0.8571 1.5000 1.7849
1.5000 0.8571 0.5000 0.8571 1.5000 1.7917 1.5000
0.8176 0.5000 1.0065 1.5000 1.1424 0.5000 0.3436
0.5000 0.5788 0.5000 0.3436 0.5000 1.1424 1.5000
1.0065 0.8312 1.5000 1.7263 1.5000 1.0635 0.5000
0.0637]
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amp_int = i_q_int + j*i_q_int
```

amp_int is the reference symbol inserted periodically into the signal after the guard interval insertion.

As it is clear from the above specification, the present invention provides methods and apparatus for generating a signal having a frame structure and methods and apparatus for frame synchronization when receiving such signals which are superior when compared with prior art systems. The frame synchronization algorithm in accordance with the present invention provides all of the properties shown in Table 1 in contrary to known frame synchronization procedures. Table 1 shows a comparison between the system in accordance with the present invention using an AM sequence as reference symbol and prior art systems (single carrier and MCM Eureka 147).

Table 1

	Single carrier (e.g. QPSK like WS)	MCM Eureka 147	MCM with AM sequence
Carrier offset allowed	no	yes	yes
Constant power achieved at Rx input	yes	no	yes
Coarse frequency offset estimation possible	no	no	yes
Coarse channel estimation possible (cluster estimation)	yes	no	yes

As can be seen from Table 1 different synchronization tasks and parameters can be derived using the frame synchronization with an AM sequence in accordance with the present invention. The frame synchronization procedure MCM Eureka 147 corresponds to the procedure described in US-A-5,191,576.

ABSTRACT

A method for generating a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, comprises the steps of performing an amplitude modulation of a bit sequence such that the envelope of the amplitude modulated bit sequence defines a reference pattern of the reference symbol and inserting the amplitude modulated bit sequence into said signal as said reference symbol. A method for frame synchronization of a signal having such a frame structure comprises the steps of receiving the signal, down-converting the received signal, performing an amplitude-demodulation of the down-converted signal in order to generate an envelope, correlating the envelope with a predetermined reference pattern in order to detect a signal reference pattern of the reference symbol in the signal, and performing the frame synchronization based on the detection of the signal reference pattern.

CLAIMS

1. A method for generating a signal having a frame structure, each frame of said frame structure comprising at least one useful symbol (12), a guard interval (14) associated to said at least one useful symbol (12) and a reference symbol (16), said method comprising the steps of:

performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of said reference symbol (16); and

inserting the amplitude modulated bit sequence into said signal as said reference symbol (16).

2. The method according to claim 1, wherein said signal is an orthogonal frequency division multiplexed signal.

3. The method according to claim 1 or 2, wherein said amplitude modulation is performed such that a mean amplitude of said reference symbol (16) substantially corresponds to a mean amplitude of the remaining signal.

4. A method for generating a multi-carrier modulated signal having a frame structure, each frame of said frame structure comprising at least one useful symbol (12), a guard interval (14) associated to said at least one useful symbol (12) and a reference symbol (16), said method comprising the steps of:

providing a bitstream (104);

mapping bits of said bitstream (104) to carriers in order to provide a sequence of spectra (108);

performing an inverse Fourier transform (110) in order to provide multi-carrier modulated symbols (112);

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associating (114) a guard interval to each multi-carrier modulated symbol;

generating said reference symbol (16) by performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of said reference symbol;

associating (116) said reference symbol (16) to a predetermined number of multi-carrier modulated symbols and associated guard intervals in order to define said frame; and

inserting said amplitude modulated bit sequence into said signal as said reference symbol (16).

5. The method according to claim 4, wherein said multi-carrier modulated signal is an orthogonal frequency division multiplex signal.

6. The method according to claim 4 or 5, wherein said amplitude modulation is performed such that a mean amplitude of said reference symbol (16) substantially corresponds to a mean amplitude of the remaining multi-carrier modulated signal.

7. The method according to one of claims 1 to 6, wherein said bit sequence is a pseudo random bit sequence having good autocorrelation characteristics.

8. The method according to one of claims 1 to 7, wherein a number of useful symbols (12) in each frame is defined depending on channel properties of a channel (122) through which the signal or the multi-carrier modulated signal is transmitted.

9. A method for frame synchronization of a signal having a frame structure, each frame of said frame structure comprising at least one useful symbol (12), a guard

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interval (14) associated with said at least one useful symbol (12) and a reference symbol (16), said method comprising the steps of:

receiving said signal;

down-converting said received signal;

performing (164) an amplitude-demodulation of said down-converted signal in order to generate an envelope;

correlating (166) said envelope with a predetermined reference pattern in order to detect the signal reference pattern of said reference symbol (16) in said signal; and

performing said frame synchronization based on the detection of said signal reference pattern.

10. The method according to claim 9, further comprising the step of performing a fast automatic gain control (162) of said received down-converted signal prior to the step of performing said amplitude-demodulation (164).

11. The method according to claim 9 or 10, wherein the step of performing (164) said amplitude-demodulation comprises the step of calculating an amplitude of said signal using the alpha_{max+} beta_{min-} method.

12. The method according to claim 9 or 10, further comprising the steps of sampling respective amplitudes of said received down-converted signal and comparing said sampled amplitudes with a predetermined threshold in order to generate a bit sequence in order to perform said amplitude demodulation.

13. The method according to claim 12, wherein the step of sampling respective amplitudes of said received down-converted signal further comprises the step of performing an over-sampling of said received down-converted

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signal.

14. The method according to any one of claims 9 to 13, further comprising the step of applying a result of the frame synchronization for a frame in said signal to at least one subsequent frame in said signal.

15. A method for frame synchronization of a multi-carrier modulated signal having frame structure, each frame of said frame structure comprising at least one useful symbol (12), a guard interval (14) associated to said at least one useful symbol (12) and a reference symbol (16), said method comprising the steps of:

receiving said multi-carrier modulated signal;

down-converting said received multi-carrier modulated signal;

performing (164) an amplitude-demodulation of said down-converted multi-carrier modulated signal in order to generate an envelope;

correlating (166) said envelope with a predetermined reference pattern in order to detect the signal reference pattern of said reference symbol in said multi-carrier modulated signal;

performing said frame synchronization based on the detection of said signal reference pattern;

extracting (136/138) said reference symbol (16) and said at least one guard interval (14) from said down-converted received multi-carrier modulated signal based on said frame synchronization;

performing (140) a Fourier transform in order to provide a sequence of spectra from said at least one useful symbol;

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de-mapping (142) said sequence of spectra in order to provide a bitstream.

16. The method according to claim 15, further comprising the step of performing (162) a fast automatic gain control of said received down-converted multi-carrier modulated signal prior to the step of performing said amplitude-demodulation.

17. The method according to claim 15 or 16, wherein the step of performing (164) said amplitude-demodulation comprises the step of calculating an amplitude of said multi-carrier modulated signal using the $alpha_{max+}$ $beta_{min-}$ method.

18. The method according to claim 15 or 16, further comprising the steps of sampling respective amplitudes of said received down-converted multi-carrier modulated signal and comparing said sampled amplitudes with a predetermined threshold in order to generate a bit sequence in order to perform said amplitude demodulation.

19. The method according to claim 18, wherein the step of sampling respective amplitudes of said received down-converted multi-carrier modulated signal further comprises the step of performing an over-sampling of said received down-converted multi-carrier modulated signal.

20. The method according to one of claims 15 to 19, further comprising the step of applying a result of the frame synchronization for a frame in said signal to at least one subsequent frame in said multi-carrier modulated signal.

21. The method according to one of claims 9 to 20, further comprising the step of detecting a location of said signal reference pattern based on an occurrence of a maximum of a correlation signal when correlating said envelope with said predetermined reference pattern.

22. The method according to claim 21, further comprising the

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steps of:

weighting a plurality of maxima of said correlation signal such that a maximum occurring first is weighted stronger than any subsequently occurring maximum; and

detecting said location of said signal reference pattern based on the greatest one of said weighted maxima.

23. The method according to claim 22, further comprising the step of:

disabling the step of performing said frame synchronization for a predetermined period of time after having switched-on a receiver (130) performing said method for frame synchronization.

24. An apparatus for generating a signal having a frame structure, each frame of said frame structure comprising at least one useful symbol (12), a guard interval (14) associated to said at least one useful symbol (12) and a reference symbol (14), said apparatus comprising:

an amplitude modulator for performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of said reference symbol (16); and

means for inserting the amplitude modulated bit sequence into said signal as said reference symbol (16).

25. The apparatus according to claim 24, wherein said signal is an orthogonal frequency division multiplexed signal.

26. The apparatus according to claim 24 or 25, wherein a mean amplitude of said reference symbol (16) substantially corresponds to a mean amplitude of the remaining signal.

27. An apparatus for generating a multi-carrier modulated

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signal having a frame structure, each frame of said frame structure comprising at least one useful symbol (12), a guard interval (14) associated to said at least one useful symbol (12) and a reference symbol (16), said apparatus comprising:

means (102) for providing a bitstream (104);

means (106) for mapping bits of said bitstream (104) to carriers in order to provide a sequence of spectra (108);

means (110) for performing an inverse Fourier transform in order to provide multi-carrier modulated symbols (112);

means (114) for associating a guard interval to each multi-carrier modulated symbol;

means for generating said reference symbol (16) comprising an amplitude modulator for performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of said reference symbol (16);

means (116) for associating said reference symbol (16) to a predetermined number of multi-carrier modulated symbols (12) and associated guard intervals (14) in order to define said frame; and

means for inserting the amplitude modulated bit sequence into said signal as said reference symbol (16).

28. The apparatus according to claim 27, wherein said multi-carrier modulated signal is an orthogonal frequency division multiplex signal.

29. The apparatus according to claim 26 or 27, wherein said means for generating said reference symbol (16) performs the amplitude modulation such that a mean amplitude of said reference symbol (16) substantially corresponds to a mean

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amplitude of the remaining multi-carrier modulated signal.

30. The apparatus according to one of claims 24 to 29, wherein said means for generating said reference symbol (16) generates a pseudo random bit sequence having good autocorrelation characteristics as said bit sequence.

31. The apparatus according to one of claims 24 to 30, comprising means for determining a number of useful symbols (12) in each frame depending on channel properties of a channel (122) through which the signal or the multi-carrier modulated signal is transmitted.

32. An apparatus for frame synchronization of a signal having a frame structure, each frame of said frame structure comprising at least one useful symbol (12), a guard interval (14) associated to said at least one useful symbol (12) and a reference symbol (16), said apparatus comprising:

receiving means (132) for receiving said signal;

a down-converter for down-converting said received signal;

an amplitude-demodulator (164) for performing an amplitude demodulation of said down-converted signal in order to generate an envelope;

a correlator (166) for correlating said envelope with a predetermined reference pattern in order to detect the signal reference pattern of said reference symbol (16) in said signal; and

means for performing said frame synchronization based on the detection of said signal reference pattern.

33. The apparatus according to claim 32, further comprising means (162) for performing a fast automatic gain control of said received down-converted signal preceding said

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amplitude-demodulator (164).

34. The apparatus according to claim 32 or 33, wherein said amplitude-demodulator (164) comprises means for calculating an amplitude of said signal using the $alpha_{max+}$ $beta_{min}$-method.

35. The apparatus according to claim 32 or 33, further comprising means for sampling respective amplitudes of said received down-converted signal, wherein said amplitude-demodulator (164) comprises means for comparing said sampled amplitudes with a predetermined threshold in order to generate a bit sequence.

36. The apparatus according to claim 35, wherein said means for sampling comprises means for over-sampling said received down-converted signal.

37. The apparatus according to one of claims 32 to 36, further comprising means for applying a result of the frame synchronization for a frame in said signal to at least one subsequent frame in said signal.

38. An apparatus for frame synchronization of a multi-carrier modulated signal having a frame structure, each frame of said frame structure comprising at least one useful symbol (12), a guard interval (14) associated to said at least one useful symbol (12) and a reference symbol (16), said apparatus comprising:

a receiver (132) for receiving said multi-carrier modulated signal;

a down-converter for down-converting said received multi-carrier modulated signal;

an amplitude-demodulator (164) for performing an amplitude-demodulation of said down-converted multi-carrier modulated signal in order to generate an envelope;

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a correlator (166) for correlating said envelope with a predetermined reference pattern in order to detect the signal reference pattern of said reference symbol (16) in said multi-carrier modulated signal;

means for performing said frame synchronization based on the detection of said signal reference pattern;

means (136/138) for extracting said reference symbol (16) and said at least one guard interval (14) from said down-converted received multi-carrier modulated signal based on said frame synchronization in order to generate said at least one useful symbol;

means (140) for performing a Fourier transform in order to provide a sequence of spectra from said at least one useful symbol; and

means (142) for de-mapping said sequence of spectra in order to provide a bitstream.

39. The apparatus according to claim 38, further comprising means (162) for performing a fast automatic gain control of said received down-converted multi-carrier modulated signal preceding said amplitude-demodulator (164).

40. The apparatus according to claim 38 or 39, wherein said amplitude-demodulator (164) comprises means for calculating an amplitude of said multi-carrier modulated signal using the alpha_{max+} beta_{min-} method.

41. The apparatus according to claim 38 or 39, further comprising means for sampling respective amplitudes of said received down-converted multi-carrier modulated signal, wherein said amplitude-demodulator (164) comprises means for comparing said sampled amplitudes with a predetermined threshold in order to generate a bit sequence.

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42. The apparatus according to claim 41, wherein said means for sampling comprises means for over-sampling said received down-converted multi-carrier modulated signal.

43. The apparatus according to one of claims 38 to 42, further comprising means for applying a result of the frame synchronization for a frame in said multi-carrier modulated signal to at least one subsequent frame in said multi-carrier modulated signal.

44. The apparatus according to one of claims 32 to 43, further comprising means for detecting a location of said signal reference pattern based on an occurrence of a maximum of a correlation signal output of said correlator (166).

45. The apparatus according to claim 44, further comprising means for weighting a plurality of maxima of said correlation signal such that a maximum occurring first is weighted stronger than any subsequently occurring maximum; and

means for detecting said location of said signal reference pattern based on the greatest one of said weighted maxima.

46. The apparatus according to claim 45, further comprising means for disabling said means for performing said frame synchronization for a predetermined period of time after having switched-on a receiver (130) comprising said apparatus for frame synchronization.

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FRAME STRUCTURE AND FRAME SYNCHRONIZATION FOR MULTICARRIER SYSTEMS

FIELD OF THE INVENTION

The present invention relates to methods and apparatus for generating a signal having a frame structure, wherein each frame of the frame structure is composed of useful symbols, a guard interval associated to each useful symbol and one reference symbol. In addition, the present invention relates to methods and apparatus for frame synchronization of signals having the above structure.

The present invention is particularly useful in a MCM transmission system (MCM = Multi-carrier modulation) using an orthogonal frequency division multiplexing (OFDM) for digital broadcasting.

BACKGROUND OF THE INVENTION

In a MCM (OFDM) transmission system the binary information is represented in the form of a complex spectrum, i.e. a distinct number of complex subcarrier symbols in the frequency domain. In the modulator a bitstream is represented by a sequence of spectra. Using an inverse Fourier-transform (IFFT) a MCM time domain signal is produced from this sequence of spectra.

In case of a transmission of this described MCM signal via a multipath channel with memory, intersymbol interference (ISI) occurs due to multipath dispersion. To avoid ISI a guard interval of fixed length is added between adjacent MCM symbols in time. The guard interval is chosen as cyclic prefix. This means that the last part of a time domain MCM symbol is placed in front of the symbol to get a periodic extension. If the fixed length of the chosen guard interval is

greater than the maximum multipath delay, ISI will not occur.

In the receiver the information which is in the frequency and time domain (MCM) has to be recovered from the MCM time domain signal. This is performed in two steps. Firstly, optimally locating the FFT window, thus eliminating the guard interval in front of each MCM time domain symbol. Secondly, performing a Fourier Transform of the sequence of useful time samples thus obtained.

As a result a sequence of spectral symbols is thus recovered. Each of the symbols contains a distinct number of information carrying subcarrier symbols. Out of these, the information bits are recovered using the inverse process of the modulator.

Performing the above described method, the following problem occurs in the receiver. The exact position of the guard interval and hence the position of the original useful parts of the time domain MCM symbols is generally unknown. Extraction of the guard interval and the subsequent FFT-transform of the resulting useful part of the time signal is not possible without additional information. To provide this additional information, a known (single carrier) sequence in the form of a (time domain) reference symbol is inserted into the time signal. With the knowledge about the positions of the reference symbols in the received signal, the exact positions of the guard intervals and thus the interesting information carrying time samples are known.

The periodical insertion of the reference symbol results in a frame structure of the MCM signal. This frame structure of a MCM signal is shown in Figure 1. One frame of the MCM signal is composed of a plurality of MCM symbols 10. Each MCM symbol 10 is formed by an useful symbol 12 and a guard interval 14 associated therewith. As shown in Figure 1, each frame comprises one reference symbol 16.

A functioning synchronization in the receiver, i.e. frame, frequency, phase, guard interval synchronization is necessary for the subsequent MCM demodulation. Consequently, the first and most important task of the base band processing in the receiver is to find and synchronize to the reference symbol.

DESCRIPTION OF THE PRIOR ART

Most prior art methods for frame synchronization have been developed for single carrier transmission over the AWGN channel (AWGN = Additive White Gaussian Noise). These prior art methods based on correlation are, without major changes, not applicable for transmission over multipath fading channels with large frequency offsets or MCM transmission systems that use, for example, an orthogonal frequency division multiplexing.

For MCM transmission systems particular frame synchronization methods have been developed.

Warner, W.D., Leung C.: OFDM/FM Frame Synchronization for Mobile Radio Data Communication, IEEE Trans. On Vehicular Technology, vol. VT-42, August 1993, pp. 302 to 313, teaches the insertion of reference symbols in the form of tones in parallel with the data into the MCM symbol. The reference symbols occupy several carriers of the MCM signal. In the receiver, the synchronization carriers are extracted in the frequency domain, after a FFT transform (FFT = fast Fourier transform) using a correlation detector. In the presence of large frequency offsets, this algorithm becomes very complex because several correlators must be implemented in parallel.

A further prior art technique is to insert a periodic reference symbol into the modulated MCM signal. This reference symbol is a CAZAC sequence (CAZAC = Constant Amplitude Zero Autocorrelation). Such techniques are taught by: Classen, F., Meyr, H.: Synchronization algorithms for an OFDM system

for mobile communication, in Codierung für Codierung für Quelle, Kanal und Übertragung: ITG-Fachbericht 130, pp. 105-114, München, October 1994, ITG, VDE-Verlag, Berlin Offenbach; Lambrette, U., Horstmannshoff, J., Meyr, H.: Techniques for Frame Synchronization on Unknown Frequency Selective Channels, Proc. Vehic. Technology Conference, 1997; Schmidl, T.M., Cox, D.C.: Low-Overhead, Low-Complexity [Burst] Synchronization for OFDM Transmission, Proc. IEEE Int. Conf. on Commun., 1996. In such systems, the receiver's processor looks for a periodic repetition. For these algorithms coarse frequency synchronization has to be achieved prior to or at least simultaneously with frame synchronization.

Van de Beek, J, Sandell, M., Isaksson, M, Börjesson, P.: Low-Complex Frame Synchronization in OFDM Systems, Proc. of the ICUPC, 1995, avoid the insertion of additional reference symbols or pilot carriers and use instead the periodicity in the MCM signal which is inherent in the guard interval and the associated cyclical extension. This method is suitable only for slowly varying fading channels and small frequency offsets.

US-A-5,191,576 relates to a method for the diffusion of digital data designed to be received notably by mobile receivers moving in an urban environment. In this method, the header of each frame of a broadcast signal having a frame structure has a first empty synchronization symbol and a second unmodulated wobbled signal forming a two-stage analog synchronization system. The recovery of the synchronization signal is achieved in an analog way, without prior extraction of a clock signal at the binary level.

EP 0631406 A relates to data signals, COFDM signals, for example, and to methods and apparatus for diffusing said signals. The COFDM signals comprises a sequence of symbols, each symbol having an useful portion and a guard interval. Two symbols of a COFDM signal are provided as synchronization symbols. One of the two symbols is a zero symbol,

whereas the other thereof is a synchronization symbol which is formed by an unmodulated multiplex of the carrier frequencies having a constant envelope. Beside the two symbols as synchronization symbols, it is taught in EP 0631406 A to modulate the pilot frequency of the data signal with a reference signal which carries the synchronization information. This reference signal modulated on the pilot frequency of the data signal can be used by a MABLR demodulator.

WO 98/00946 A relates to a system for a timing and frequency synchronization of OFDM signals. Two OFDM training symbols are used to obtain full synchronization in less than two data frames. The OFDM training symbols are placed into the OFDM signal, preferably at least once every frame. The first OFDM training symbol is produced by modulating the even-numbered OFDM sub-carriers whereas the odd-numbered OFDM sub-carriers are suppressed. Thus, in accordance with WO 98/00946 A, the first OFDM training symbol is produced by modulating the even-numbered carriers of this symbol with a first predetermined PN sequence.

Moose: "A technique for orthogonal frequency division multiplexing frequency offset correction", IEEE TRANSACTIONS ON COMMUNICATIONS, Vo. 42, No. 10, October 1994, pages 2908 to 2914, teaches methods for correcting frequency offsets in OFDM digital communications. The methods involve repetition of a data symbol and comparison of the phases of each of the carriers between the successive symbols. The phase shift of each of the carriers between the repeated symbols is due to the frequency offset since the modulation phase values are not changed in the repeated symbols.

Keller; Hanzo: "Orthogonal frequency division multiplex synchronization techniques for wireless local area networks", IEEE INTERNATIONAL SYMPOSIUM ON PERSONAL, INDOOR AND MOBILE RADIO COMMUNICATIONS, October 15, 1996, pages 963 to 967, teach frequency acquisition, frequency tracking, symbol synchronization and frame synchronization techniques. Regarding the frame synchronization, it is taught to use a reference

symbol which consists of repetitive copies of a synchronization pattern of pseudo-random samples. The frame synchronization is achieved by autocorrelation techniques using the periodic synchronization segments such that for the synchronization algorithms proposed no a priori knowledge of the synchronization sequences is required.

The methods for frame synchronization available up to date require either prior achieved frequency synchronization or become very complex when the signal in the receiver is corrupted by a large frequency offset.

If there is a frequency offset in the receiver, as can easily be the case when a receiver is powered-on and the frequency synchronization loop is not yet locked, problems will occur. When performing a simple correlation there will only be noise at the output of the correlator , i.e. no maximum can be found if the frequency offset exceeds a certain bound. The size of the frequency offset depends on the length (time) of the correlation to be performed, i.e. the longer it takes, the smaller the allowed frequency offset becomes. In general, frequency offset increases implementation complexity.

Frequency offsets occur after power-on or later due to frequency deviation of the oscillators used for down-conversion to baseband. Typical accuracies for the frequency of a free running local oscillator (LO) are at ±50 ppm of the carrier frequency. With a carrier frequency in S-band (e.g. 2.34 GHz) there will be a maximum LO frequency deviation of above 100 kHz (117.25 kHz). A deviation of this magnitude puts high demands on the above methods.

In the case of multipath impaired transmission channel, a correlation method yields several correlation maxima in addition to the distinct maximum for an AWGN channel. The best possible frame header position, i.e. the reference symbol, has to be selected to cope with this number of maxima. In multipath channels, frame synchronization methods with cor-

relations can not be used without major changes. Moreover, it is not possible to use data demodulated from the MCM system, because the demodulation is based on the knowledge of the position of the guard interval and the useful part of the MCM symbol.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method and an apparatus for generating a signal having a frame structure that allow a frame synchronization after the signals have been transmitted even in the case of a carrier frequency offset or in the case of a transmission via a multipath fading channel.

It is a further object of the present invention to provide a method and an apparatus for frame synchronization of a signal having a frame structure even in the case of a carrier frequency offset.

In accordance with a first aspect, the present invention provides a method for generating a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the method comprising the steps of performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the reference symbol and inserting the amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a second aspect, the present invention provides a method for generating a multi-carrier modulated signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the method comprising the steps of:

providing a bitstream;

mapping bits of the bitstream to carriers in order to provide a sequence of spectra;

performing an inverse Fourier transform in order to provide multi-carrier modulated symbols;

associating a guard interval to each multi-carrier modulated symbol;

generating the reference symbol by performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the reference symbol;

associating the reference symbol to a predetermined number of multi-carrier modulated symbols and associated guard intervals in order to define the frame; and

inserting said amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a third aspect, the present invention provides a method for frame synchronization of a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated with the at least one useful symbol and a reference symbol, the method comprising the steps of:

receiving the signal;

down-converting the received signal;

performing an amplitude-demodulation of the down-converted signal in order to generate an envelope;

correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the signal; and

performing the frame synchronization based on the detection of the signal reference pattern.

In accordance with a fourth aspect, the present invention provides a method for frame synchronization of a multi-carrier modulated signal having frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the method comprising the steps of:

receiving the multi-carrier modulated signal;

down-converting the received multi-carrier modulated signal;

performing an amplitude-demodulation of the down-converted multi-carrier modulated signal in order to generate an envelope;

correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the multi-carrier modulated signal;

performing the frame synchronization based on the detection of the signal reference pattern;

extracting the reference symbol and the at least one guard interval from the down-converted received multi-carrier modulated signal based on the frame synchronization;

performing a Fourier transform in order to provide a sequence of spectra from the at least one useful symbol;

de-mapping the sequence of spectra in order to provide a bitstream.

In accordance with a fifth aspect, the present invention provides an apparatus for generating a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising an amplitude modulator for performing an amplitude modulation of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the reference symbol; and [¶ break deleted] means for inserting the amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a sixth aspect, the present invention provides an apparatus for generating a multi-carrier modulated signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising:

means for providing a bitstream;

means for mapping bits of the bitstream to carriers in order to provide a sequence of spectra;

means for performing an inverse Fourier transform in order to provide multi-carrier modulated symbols;

means for associating a guard interval to each multi-carrier modulated symbol;

means for generating the reference symbol by an amplitude modulator for performing an amplitude modulation

of a bit sequence, the envelope of the amplitude modulated bit sequence defining the reference pattern of the reference symbol;

means for associating the reference symbol to a predetermined number of multi-carrier modulated symbols and associated guard intervals in order to define the frame; and

means for inserting the amplitude modulated bit sequence into said signal as said reference symbol.

In accordance with a seventh aspect, the present invention provides an apparatus for frame synchronization of a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising:

receiving means for receiving the signal;

a down-converter for down-converting the received signal;

an amplitude-demodulator for performing an amplitude demodulation of the down-converted signal in order to generate an envelope;

a correlator for correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the signal; and

means for performing the frame synchronization based on the detection of the signal reference pattern.

In accordance with [a] <u>an</u> eighth aspect, the present invention provides an apparatus for frame synchronization of a multi-carrier modulated signal having a frame structure,

each frame of the frame structure comprising at least one useful symbol, a guard interval associated to the at least one useful symbol and a reference symbol, the apparatus comprising:

a receiver for receiving the multi-carrier modulated signal;

a down-converter for down-converting the received multi-carrier modulated signal;

an amplitude-demodulator for performing an amplitude-demodulation of the down-converted multi-carrier modulated signal in order to generate an envelope;

a correlator for correlating the envelope with a predetermined reference pattern in order to detect the signal reference pattern of the reference symbol in the multi-carrier modulated signal;

means for performing the frame synchronization based on the detection of the signal reference pattern;

means for extracting the reference symbol and the at least one guard interval from the down-converted received multi-carrier modulated signal based on the frame synchronization in order to generate the at least one useful symbol;

means for performing a Fourier transform in order to provide a sequence of spectra from the at least one useful symbol; and

means for de-mapping the sequence of spectra in order to provide a bitstream.

The present invention provides a novel structure of the reference symbol along with a method to determine the position of the reference symbol and thus the start of a frame in a

signal having a frame structure as shown for example in Figure 1.

The invention relates to a method for finding frame headers independently of other synchronization information and thus for positioning the FFT windows correctly. This includes the extraction of a guard interval. The method is based on the detection of a known reference symbol of the frame header in the reception signal, e.g. in the digital complex baseband. The new frame synchronization will be performed as the first synchronization task.

Synchronization to the reference symbol, i.e. the frame header is the first step to initiate radio reception. The reference symbol is structured to accomplish this. The information contained in the reference symbol must therefore be independent of other synchronization parameters, e.g. frequency offset. For this reason, in accordance with the present invention, the form of the reference symbol selected is an amplitude modulated sequence (AM sequence) in the complex baseband. Thus, the information contained in the reference symbol is only that given in the amplitude and not that in the phase. Note that the phase information will be corrupted by a possible frequency offset. In preferred embodiments of the present invention, the AM information is constructed from a bit sequence with special features. The information sequence is selected in a way which makes it easy and secure to find it in the time domain. A bit sequence with good autocorrelation properties is chosen. Good autocorrelation properties means a distinct correlation maximum in a correlation signal which should be as white as possible.

A pseudo random bit sequence (PRBS) having good autocorrelation properties meets the above requirements.

Using the envelope of the signal to carry bit information offers additional flexibility. First it has to be decided which envelope values should correspond to the binary values

of 0 and 1. The parameters are mean amplitude and modulation rate. Attention should be paid to selecting the mean amplitude of the reference symbol (performance) identically to the mean amplitude of the rest of the frame. This is due to the amplitude normalization (AGC; AGC = Automatic Gain Control) performed in the receiver. It is also possible to select the mean amplitude of the reference symbol higher than the mean signal amplitude, but then care has to be taken that the time constant of the AGC (1/sensitivity) is selected high enough to secure that the strong (boosted) signal of the reference symbol does not influence the AGC control signal and thus attenuate the signal following the reference symbol.

Another degree of freedom can be characterized as modulation degree d. This parameter is responsible for the information density of the modulating signal mod(t) formed out of the binary sequence bin(t) as follows: mod(t) = bin(t/d). This modulation degree can be chosen as free parameter fixed by an integer or real relation to the sampling rate. It is appropriate to choose the modulation degree d as an integer value because of the discrete values of the binary sequence:

```
d = 1: mod(m)  = bin(m)
d = 2: mod(m)  = bin(m/2)      for m even
               = bin_int(m/2)  for m odd
d = 3: mod(m)  = bin(m/3)      for  m  =  0,  ±3,  ±6,  ±9,
                 bin_int(m/3)  else
```

The signal values bin_int(m/d) are computed from the binary sequence bin(m) by ideal interpolation (between the discrete integer values m) with the factor of d. This is similar to an ideal sampling rate expansion (with sin(x)/x interpolation), but the sampling rate remains, only less bits of the binary sequence bin(m) correspond to the resulting interpolated sequence mod(m). This parameter m indicates the discrete time.

With increasing m the modulating signal mod(t) is expanded in time relative to the basic binary sequence, this results in a bandwidth compression of the resulting AM spectrum with regard to the basic binary sequence. A time expansion by a factor 2 results in a bandwidth compression by the same factor 2. In addition to the bandwidth compression, a further advantage of a higher modulation degree d is a reduced complexity of the search method in the receiver due to the fact that only each dth sample has a corresponding binary value. Choosing the factor d = 1 is not preferred since this would result in aliasing due to disregard of the sampling theorem. For this reason, in a preferred embodiment of the present invention d is chosen to be 2.

The choice of length and repetition rate of the reference symbol is, on the one hand, dominated by the channel properties, e.g. the channel's coherence time. On the other hand the choice depends on the receiver requirements concerning mean time for initial synchronization and mean time for resynchronization after synchronization loss due to a channel fade.

In the receiver, the first step after the down-conversion of the received signal is to perform an amplitude-demodulation of the down-converted signal in order to generate an envelope, i.e. in order to determine the amplitude of the signal. This envelope is correlated with a replica reference pattern in order to detect the signal reference pattern of the reference symbol in the signal. In the case of a AWGN channel, the result of this correlation will be a white noise signal with zero mean value and with a clearly visible (positive) maximum. In the case of a multipath channel, several maxima will occur in the correlation signal computed by this correlation. In the former case, the location of the reference symbol is determined based on the signal maximum, whereas in the latter case a weighting procedure is performed in order to find out the maximum corresponding to the location of the reference symbol.

Thus, the present invention shows how to find a reference symbol by a detection method which is simple. Furthermore, the present invention can be used for one-carrier or multi-carrier systems. The present invention is particularly useful in multi-carrier modulation systems using an orthogonal frequency division multiplexing, for example in the field of digital broadcasting. The synchronization methods according to the present invention are independent of other synchronization steps. Since the information needed for the synchronization is contained in the envelope of the preamble, i.e. the reference symbol, the reference symbol is independent of possible frequency offsets. Thus, a derivation of the correct down sampling timing and the correct positioning of the FFT window can be achieved. The reference symbol of the present invention can be detected even if the frequency synchronization loop is not yet locked or even in the case of a carrier frequency offset. The frame synchronization method in accordance with the present invention is preferably performed prior to other and without knowledge of other synchronization efforts.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following, preferred embodiments of the present invention will be explained in detail on the basis of the drawings enclosed, in which:

Figure 1 shows a schematic view of a signal having a frame structure;

Figure 2 shows a block diagram of a MCM system to which the present invention can be applied;

Figure 3 shows a schematic block diagram of a frame and frequency synchronization system in a MCM receiver;

Figure 4 shows a schematic diagram of an apparatus for frame synchronization; and

Figure 5 shows a typical channel impulse response of a single frequency network in S-band.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Although the present invention is explained mainly referring to a MCM system, it is obvious that the present invention can be used in connection with different signal transmissions that are based on different kinds of modulation.

Figure 2 shows a MCM system overview on the basis of which the present invention will be described in detail. At 100 a MCM transmitter is shown that substantially corresponds to a prior art MCM transmitter except for the kind of the reference symbol being added to each frame of a MCM signal. A description of such a MCM transmitter can be found, for example, in William Y. Zou, Yiyan Wu, "COFDM: AN OVERVIEW", IEEE Transactions on Broadcasting, vol. 41, No. 1, March 1995.

A data source 102 provides a serial bitstream 104 to the MCM transmitter. The incoming serial bitstream 104 is applied to a bit-carrier mapper 106 which produces a sequence of spectra 108 from the incoming serial bitstream 104. An inverse fast Fourier transform (FFT) 110 is performed on the sequence of spectra 108 in order to produce a MCM time domain signal 112. The MCM time domain signal forms the useful MCM symbol of the MCM time signal. To avoid intersymbol interference (ISI) caused by multipath distortion, a unit 114 is provided for inserting a guard interval of fixed length between adjacent MCM symbols in time. In accordance with a preferred embodiment of the present invention, the last part of the useful MCM symbol is used as the guard interval by placing same in front of the useful symbol. The resulting MCM symbol is shown at 115 in Figure 2 and corresponds to the MCM symbol 10 depicted in Figure 1.

In order to obtain the final frame structure shown in Figure 1, a unit 116 for adding a reference symbol for each predetermined number of MCM symbols is provided.

In accordance with the present invention, the reference symbol is an amplitude modulated bit sequence. Thus, an amplitude modulation of a bit sequence is performed such that the envelope of the amplitude modulated bit sequence defines a reference pattern of the reference symbol. This reference pattern defined by the envelope of the amplitude modulated bit sequence has to be detected when receiving the MCM signal at a MCM receiver. In a preferred embodiment of the present invention, a pseudo random bit sequence having good autocorrelation properties is used as the bit sequence for the amplitude modulation.

The choice of length and repetition rate of the reference symbol depends on the properties of the channel through which the MCM signal is transmitted, e.g. the coherence time of the channel. In addition, the repetition rate and the length of the reference symbol, in other words the number of useful symbols in each frame, depends on the receiver requirements concerning mean time for initial synchronization and mean time for resynchronization after synchronization loss due to a channel fade.

The resulting MCM signal having the structure shown at 118 in Figure 2 is applied to the transmitter front end 120. Roughly speaking, at the transmitter front end 120, a digital/analog conversion and an up-converting of the MCM signal is performed. Thereafter, the MCM signal is transmitted through a channel 122.

Following, the mode of operation of a MCM receiver 130 is shortly described referring to Figure 2. The MCM signal is received at the receiver front end 132. In the receiver front end 132, the MCM signal is down-converted and, furthermore, a analog/digital conversion of the down-converted

signal is performed. The down-converted MCM signal is provided to a frame synchronization unit 134. The frame synchronization unit 134 determines the location of the reference symbol in the MCM symbol. Based on the determination of the frame synchronization unit 134, a reference symbol extracting unit 136 extracts the framing information, i.e. the reference symbol, from the MCM symbol coming from the receiver front end 132. After the extraction of the reference symbol, the MCM signal is applied to a guard interval removal unit 138. The mode of operation of the frame synchronization unit 134 which represents the present invention will be described in detail referring to Figures 3 and 4 hereinafter.

The result of the signal processing performed hereherto in the MCM receiver is the useful MCM symbols.

The useful MCM symbols output from the guard interval removal unit 138 are provided to a fast Fourier transform unit 140 in order to provide a sequence of spectra from the useful symbols. Thereafter, the sequence of spectra is provided to a carrier-bit mapper 142 in which the serial bitstream is recovered. This serial bitstream is provided to a data sink 144.

Following, the mode of operation of the frame synchronization unit will be described in detail referring to Figures 3 and 4. Figure 3 represents a further high level diagram of an apparatus for frame synchronization of a MCM signal. In the receiver front end 150, the incoming MCM signal is down-converted. In Figure 3, an analog/digital converter 152 is shown separated from the receiver front end 150. The output signal of the analog/digital converter 152 is applied to a frame synchronization unit 154. This frame synchronization unit 154 performs the frame synchronization in accordance with the present invention which will be described in detail referring to Figure 4 hereinafter. Depending on the frame synchronization of the frame synchronization unit 154, a MCM

demodulator 156 demodulates the MCM signal in order to provide a demodulated serial bitstream.

As shown in Figure 3, the described reference symbol in accordance with the present invention can also be used for a coarse frequency synchronization of the MCM signal. Namely, the frame synchronization unit 154 also serves as a coarse frequency synchronization unit for determining a coarse frequency offset of the carrier frequence caused, for example, by a difference of the frequencies between the local oscillator of the transmitter and the local oscillator of the receiver. The determined frequency offset is used in order to perform a coarse frequency correction at a point 158.

In Figure 4, a detailed schematic of the frame synchronization in accordance with the present application is depicted. A MCM signal transmitted through the channel 122 is received at the receiver RF-front end 132. The down-converted MCM signal is sampled at the receiver front end 132 and is, in the preferred embodiment, provided to a fast running automatic gain control (time constant < MCM symbol duration) in order to eliminate fast channel fluctuations (channel coherence time ≈ MCM symbol duration). The fast AGC 162 is used in addition to the normally slow AGC in the signal path, in the case of transmission over a multipath channel with long channel impulse response and frequency selective fading. The fast AGC adjusts the average amplitude range of the signal to the known average amplitude of the reference symbol. The so processed symbol is provided to an amplitude determining unit 164.

The amplitude determining unit 164 can use the simple alpha$_{max+}$ beta$_{min-}$ method in order to calculate the amplitude of the signal. This method is described for example in Palachels A.: DSP-mP Routine Computes Magnitude, EDN, October 26, 1989; and Adams, W. T., and Bradley, J.: Magnitude Approximations for Microprocessor Implementation, IEEE Micro, Vol. 3, No. 5, October 1983.

The output signal of the amplitude determining unit 164 is applied to a correlator 166. In the correlator 166, a cross correlation between the amplitude signal output from the amplitude determining unit 164 and a known ideal amplitude information is computed. The known ideal amplitude information is stored in the correlator. For both, the amplitude and the known ideal amplitude information, their amplitudes are symmetrically to zero relative to their average amplitude.

In the ideal AWGN case, the result will be a white noise signal with zero mean value and with a clearly visible positive maximum. In this ideal AWGN case, the position of the single maximum is evaluated in a maximum position unit 172. On the basis of this evaluation, the reference symbol and the guard intervals are extracted from the MCM signal in a combined reference symbol/guard extraction unit 136/138. Although these units are shown as a combined unit 136/138 in Figure 4, it is clear that separate units can be provided. The MCM signal is transmitted from the RF front end 150 to the reference symbol/guard extraction unit 136/138 via a low pass filter 174.

In the case of time spreading encountered in a multipath channel, several maxima corresponding to the number of clusters in the channel impulse response occur in the output signal of the correlator. A schematic view of three such clusters located in a time window of maximum about 60 microseconds is shown in Figure 5. Out of the several maxima caused by the time spreading encountered in a multipath channel, the best one has to be selected as the position of the frame header, i.e. the reference symbol. Therefore, a threshold unit 168 and a weighting unit 170 are provided between the correlator 166 and the maximum position unit 172. The threshold unit 168 is provided to remove maxima having an amplitude below a predetermined threshold. The weighting unit 164 is provided in order to perform a weighting procedure on the remaining maxima such that the maximum corresponding to the reference symbol can be determined. An exam-

plary weighting procedure performed in the weighting unit 170 is as follows.

The first significant maximum is considered to be the best one. The output signal of the correlator is observed from the first detected maximum onwards for the maximum length of the channel impulse response and an amplitude weighting function is applied to the signal. Because the actual channel impulse response length is unknown, the following fact can be remembered. During system design, the length of the channel impulse response has to be investigated. In a MCM system, the guard interval shall be equal or longer than the maximum expected channel impulse response. For this reason, the part (interval with lI samples, lI corresponding to the maximum expected channel impulse response, i.e. the guard interval length) of the correlation output signal starting with the first maximum,

$$I_{k0}(n) = r(k_0+n),\quad 0 \# n \# l_I - 1 \qquad \text{(Eq.1)}$$

with k_0 being the position of the first maximum, will be examined to find the best frame start position. The above signal part is weighted with the function

$$W(n) = 10^{-\frac{weight\_dB}{10}\frac{n}{l_I-1}} \qquad \text{(Eq.2)}$$

The position (n_{max}) of the maximum in the resulting signal interval

$$I_{k0,weighted}(n) = [r(k_0+n)\ W(n)] = [r(k_0+n)\ 10^{-\frac{weight\_dB}{10}\frac{n}{l_I-1}}]$$

$$0 \# n \# l_I - 1 \qquad \text{(Eq.3)}$$

will be chosen as best frame start position.

r(k) designates the output signal of the correlator (166) at the time k. The signal is present with a clock frequency which is determined by the multiplication: oversampling fac-

tor * subcarrier symbol frequency. The parameter k designates the discrete time in sample clocks. This signal is windowed with information from the threshold unit 168. An interval having the length of l_I values is extracted from the signal r(k). The first value being written into the interval is the correlation start value at the time k_0, at which the output value $r(k_0)$ exceeds the threshold value of the threshold unit 168 for the first time. The interval with the windowed signal is designated by the term $I(k_0)$. The parameter n designates the relative time, i.e. position, of a value inside the interval.

Using the described weighting operation, the earlier correlation maxima are more likely to be chosen as right frame start position. A later coming maximum will only be chosen as frame start position, if the value of the maximum is significantly higher than the earlier one. This operation is applicable especially for MCM, because here it is better to detect the frame start positions some samples too early than some samples too late. Positioning the frame start some samples too early leads to positioning the FFT window a little bit into the guard interval, this contains information of the same MCM symbol and therefore leads to little effects. If the frame start position is detected some samples too late, then the FFT window includes some samples of the following guard interval. This leads to a more visible degradation, because the following guard interval contains information of the following MCM symbol (ISI occurs).

It is important to know that the first visible correlation maximum after receiver power-on does not necessarily correspond to the first CIR (channel impulse response) cluster. It is possible that it is corresponding to a later cluster, see Figure 5. For this reason during power-on one should wait for a second frame start before starting demodulation.

It is clear that amplitude determining methods different from the described $alpha_{max+}$ $beta_{min-}$ method can be used. For simplification, it is possible to reduce the amplitude cal-

culation to a detection as to whether the current amplitude is above or below the average amplitude. The output signal then consists of a -1/+1 sequence which will be correlated with a known bit sequence, also in -1/+1 values. This correlation can easily be performed using a simple integrated circuit (IC).

In addition, an oversampling of the signal received at the RF front end can be performed. For example, the received signal can be expressed with two times oversampling.

This oversampled signal is passed to a fast running AGC to eliminate fast channel fluctuations before the amplitude of the signal is calculated. The amplitude information will be hard quantized. Values larger than the mean amplitude, mean amplitude is 1, will be expressed as +1, values smaller than the mean amplitude will be expressed as -1. This -1/+1 signal is passed to the correlator that performs a cross correlation between the quantized signal and the stored ideal amplitude values of the reference symbol:

```
amp_sto(k) = 2*bin(k/4),
   if k = 2(oversampling factor) * 2(interpolation factor) *
   1,2,3...92
   (92 for 184 reference symbol and interpolation factor 2)
amp_sto(k) = 0, else, k <= 2(oversampling factor)
   *2(interpolation factor) * 92
   (first part of amp_sto = [0 0 0 -1 0 0 0 1 0 0 0 1 0 0 0
   -1      0 .....  ]).
```

With this algorithm a correlation maximum of 92 is achievable.

Again, the maxima in the correlator output signal correspond to different frame start positions due to different multipath clusters. In this signal with various maxima the best frame start position has to be chosen. This is done in the following steps: The output of the correlator is given to a threshold detection. If the signal first time exceeds the

threshold (a threshold of 50 has proved to be applicable) the best position search algorithm is initialized. The correlator output signal in the interval following the threshold exceeding value will be weighted with the weighting function, see above. The position of the resulting maximum in the weighted signal will be chosen as best frame start position. With the knowledge about the best frame start position the guard interval extraction and the following MCM demodulation will be performed.

Some more efforts can be carried out to increase frame synchronization accuracy. These methods will be explained in the following.

A postprocessing of the frame start decision is performed in order a) to increase the reliability of the frame synchronization; b) to secure that no frame start position is disregarded; and c) to optimize the frame start position in case of varying CIR cluster positions.

Using information of other frame start positions. It is known that in front of each frame a reference symbol is inserted into the signal. If the position of the currently detected frame start has changed significantly regarding the last detected frame start, demodulation of the two frames in total and completely independent from each other is possible. It is also possible to buffer the last signal frame and to perform the required shift of the frame start position step by step with the MCM symbols of the frame. This results in an interpolative positioning of the single MCM symbols including simultaneous asynchronous guard interval extraction for the different MCM symbols.

Such an interpolative positioning of the FFT window is also possible if one frame start position is missing, i. e. the frame start has not been detected. If one frame start position is missing the guard interval extraction can be performed the same way as in the frame before without large performance degradation. This is due to the normally only

slowly varying CIR cluster positions, but only if the signal strength is good enough. Stopping demodulation and waiting for the next detected frame start position is also imaginable but not desirable because of the long interrupt.

What follows is an example of a reference symbol of 184 samples (subcarrier symbols) as provided by the inventive apparatus for generating a signal having a frame structure.

The underlying binary sequence of length 92 is:

```
bin = [0 1 1 0 1 1 0 1 0 1 1 0 1 0 1 0
       0 0 1 1 1 0 0 0 0 0 0 0 0 1 1 0
       1 1 1 1 1 0 0 0 1 1 1 0 0 0 0 0
       0 0 1 1 1 0 1 1 1 0 0 1 1 0 1 1
       1 0 1 1 0 1 0 1 0 1 1 0 1 1 0 1
       1 0 1 0 0 0 0 1 0 1 1 0]
```

The modulated binary sequence is:

```
i_q = [0.5 1.5 1.5 0.5 1.5 1.5 0.5 1.5 0.5 1.5 1.5 0.5 1.5
       0.5 1.5 0.5 0.5 0.5 1.5 1.5 1.5 0.5 0.5 0.5 0.5 0.5
       0.5 0.5 0.5 1.5 1.5 0.5 1.5 1.5 1.5 1.5 1.5 0.5 0.5
       0.5 1.5 1.5 1.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 1.5 1.5
       1.5 0.5 1.5 1.5 1.5 0.5 0.5 1.5 1.5 0.5 1.5 1.5 1.5
       0.5 1.5 1.5 0.5 1.5 0.5 1.5 0.5 1.5 1.5 0.5 1.5 1.5
       0.5 1.5 0.5 1.5 0.5 0.5 0.5 0.5 1.5 0.5 1.5 1.5 0.5]
```

This modulated binary sequence i_q is interpolated in order to produce an interpolated sequence i_q_int:

```
i_q_int = [0.5000 1.0635 1.5000 1.7195 1.5000 0.8706 0.5000
           0.8571 1.5000 1.7917 1.5000 0.8108 0.5000 1.0392
           1.5000 1.0392 0.5000 0.8108 1.5000 1.7984 1.5000
           0.8108 0.5000 1.0460 1.5000 0.9997 0.5000 0.9603
           1.5000 1.1424 0.5000 0.3831 0.5000 0.4293 0.5000
           0.9997 1.5000 1.5769 1.5000 1.5769 1.5000 1.0065
           0.5000 0.3899 0.5000 0.5325 0.5000 0.4931 0.5000
           0.4999 0.5000 0.4931 0.5000 0.5325 0.5000 0.3967
```

0.5000	0.9603	1.5000	1.7522	1.5000	0.8571	0.5000
0.8965	1.5000	1.6422	1.5000	1.4669	1.5000	1.4737
1.5000	1.6096	1.5000	0.9929	0.5000	0.4226	0.5000
0.4226	0.5000	0.9997	1.5000	1.5769	1.5000	1.5769
1.5000	1.0065	0.5000	0.3899	0.5000	0.5325	0.5000
0.4931	0.5000	0.4931	0.5000	0.5325	0.5000	0.3899
0.5000	1.0065	1.5000	1.5701	1.5000	1.6096	1.5000
0.8965	0.5000	0.8965	1.5000	1.6096	1.5000	1.5633
1.5000	1.0392	0.5000	0.2867	0.5000	0.9929	1.5000
1.7454	1.5000	0.8571	0.5000	0.9033	1.5000	1.6028
1.5000	1.6028	1.5000	0.9033	0.5000	0.8503	1.5000
1.7917	1.5000	0.8108	0.5000	1.0460	1.5000	0.9929
0.5000	0.9929	1.5000	1.0460	0.5000	0.8108	1.5000
1.7917	1.5000	0.8571	0.5000	0.8571	1.5000	1.7849
1.5000	0.8571	0.5000	0.8571	1.5000	1.7917	1.5000
0.8176	0.5000	1.0065	1.5000	1.1424	0.5000	0.3436
0.5000	0.5788	0.5000	0.3436	0.5000	1.1424	1.5000
1.0065	0.8312	1.5000	1.7263	1.5000	1.0635	0.5000
0.0637]						

```
amp_int = i_q_int + j*i_q_int
```

amp_int is the reference symbol inserted periodically into the signal after the guard interval insertion.

As it is clear from the above specification, the present invention provides methods and apparatus for generating a signal having a frame structure and methods and apparatus for frame synchronization when receiving such signals which are superior when compared with prior art systems. The frame synchronization algorithm in accordance with the present invention provides all of the properties shown in Table 1 in contrary to known frame synchronization procedures. Table 1 shows a comparison between the system in accordance with the present invention using an AM sequence as reference symbol and prior art systems (single carrier and MCM Eureka 147).

Table 1

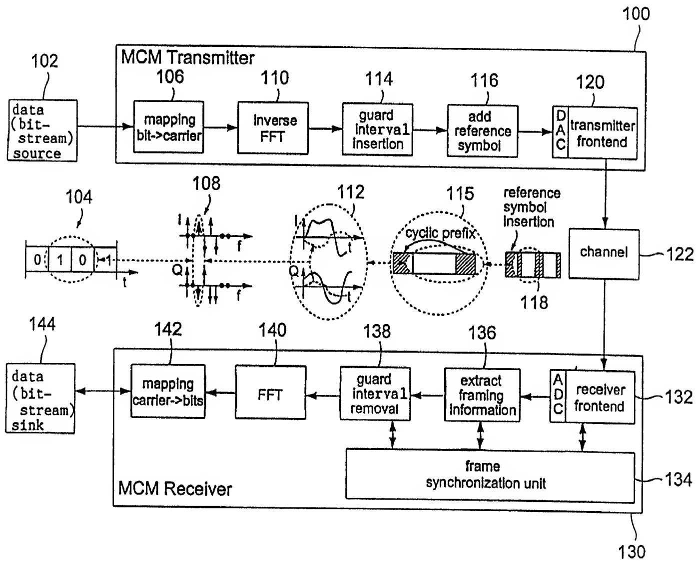
	Single carrier (e.g. QPSK like WS)	MCM Eureka 147	MCM with AM sequence
Carrier offset allowed	no	yes	yes
Constant power achieved at Rx input	yes	no	yes
Coarse frequency offset estimation possible	no	no	yes
Coarse channel estimation possible (cluster estimation)	yes	no	yes

As can be seen from Table 1 different synchronization tasks and parameters can be derived using the frame synchronization with an AM sequence in accordance with the present invention. The frame synchronization procedure MCM Eureka 147 corresponds to the procedure described in US-A-5,191,576.

[METHOD AND APPARATUS FOR GENERATING A SIGNAL HAVING A FRAME STRUCTURE AND METHOD AND APPARATUS FOR FRAME SYNCHRONIZATION]

ABSTRACT

A method for generating a signal having a frame structure, each frame of the frame structure comprising at least one useful symbol [(12)], a guard interval [(14)] associated to the at least one useful symbol [(12)] and a reference symbol [(16)], comprises the [step] steps of performing an amplitude modulation of a bit sequence such that the envelope of the amplitude modulated bit sequence defines a reference pattern of the reference symbol [(16)] and inserting the amplitude modulated bit sequence into said signal as said reference symbol. A method for frame synchronization of a signal having such a frame structure comprises the steps of receiving the signal, down-converting the received signal, performing [(164)] an amplitude-demodulation of the down-converted signal in order to generate an envelope, correlating [(166)] the envelope with a predetermined reference pattern in order to detect a signal reference pattern of the reference symbol [(16)] in the signal, and performing the frame synchronization based on the detection of the signal reference pattern.



100
MCM Transmitter
102
data (bit-stream) source
106
mapping bit->carrier
110
inverse FFT
114
guard interval insertion
116
add reference symbol
120
DAC
transmitter frontend
104
0 1 0 1
t
108
I
Q
f
112
t
115
cyclic prefix
reference symbol insertion
118
channel
122
144
data (bit-stream) sink
142
mapping carrier->bits
140
FFT
138
guard interval removal
136
extract framing information
ADC
receiver frontend
132
frame synchronization unit
134
MCM Receiver
130

FIG.2

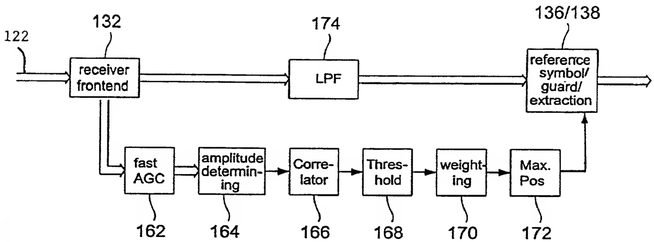

122
132
receiver frontend
174
LPF
136/138
reference symbol/ guard/ extraction
fast AGC
amplitude determin-ing
Corre-lator
Thres-hold
weight-ing
Max. Pos
162
164
166
168
170
172

FIG.4

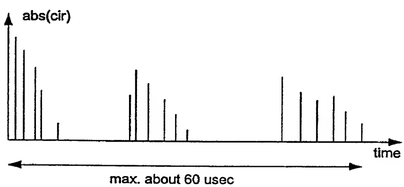

abs(cir)
time
max. about 60 usec

FIG.5

TH980402 PUS

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Filing Date	
Group Art Unit	
Examiner Name	

As a below named Inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

Frame Structure and Frame Synchronization for Multicarrier Systems

(Title of the Invention)

the specification of which

☐ is attached hereto

OR

☑ was filed on (MM/DD/YYYY) 04/14/98 as United States Application Number or PCT International Application Number PCT/EP98/02169 and was amended on (MM/DD/YYYY) ______ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			☐	☐	☑
			☐	☐	☑
			☐	☐	☐
			☐	☐	☐

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)

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DECLARATION — Utility or Design Patent Application

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U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number *(if applicable)*

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: ☐ Customer Number [ ] → *Place Customer Number Bar Code Label here*
OR
☑ Registered practitioner(s) name/registration number listed below

Name	Registration Number	Name	Registration Number
David S. Abrams	22,576	Stacey J. Longanecker	33,952
Robert H. Berdo	19,415	Joseph J. Buczynski	35,084
Alfred N. Goodman	26,458	Wayne C. Jaeschke, Jr.	38,503
Mark S. Bicks	28,770	Tara Laster Hoffman	P-46,510
John E. Holmes	29,392	Jeffrey J. Howell	46,402
Garrett V. Davis	32,023	Marcus R. Mickney	44,941
Lance G. Johnson	32,531	Christian C. Michel	46,300

☐ Additional registered practitioner(s) named on supplemental Registered Practitioner Information sheet PTO/SB/02C attached hereto.

Direct all correspondence to: ☐ Customer Number or Bar Code Label [ ] OR ☑ Correspondence address below

Name	John E. Holmes				
Address	Roylance, Abrams, Berdo & Goodman, L.L.P.				
Address	1300 19th Street, N.W., Suite 600				
City	Washington	State	D.C.	ZIP	20036
Country	USA	Telephone	(202)659-9076	Fax	(202)659-9344

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Ernst	Eberlein

Inventor's Signature						Date	
Residence: City	Grossenseebach	State		Country	Germany	Citizenship	German
Post Office Address	Waldstrasse 28 b						
Post Office Address							
City	Grossenseebach	State		ZIP	D-91091	Country	Germany

☐ Additional inventors are being named on the ____ supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

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ADDITIONAL INVENTOR(S)
Supplemental Sheet
Page 2 of 2

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])						Family Name or Surname	
Albert						Heuberger	
Inventor's Signature						Date	
Residence: City	Erlangen	State		Country	Germany	Citizenship	German
Post Office Address	Hausaeckerweg 18						
Post Office Address							
City	Erlangen	State		ZIP	D-91056	Country	Germany

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])						Family Name or Surname	
Heinz						Gerhaeuser	
Inventor's Signature						Date	
Residence: City	Waischenfeld	State		Country	Germany	Citizenship	German
Post Office Address	Saugendorf 17						
Post Office Address							
City	Waischenfeld	State		ZIP	D-91344	Country	Germany

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])						Family Name or Surname	
Inventor's Signature						Date	
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		ZIP		Country	

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Alfred N. Goodman	26,458	Wayne C. Jaeschke, Jr.	38,503
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Garrett V. Davis	32,023	Marcus R. Mickney	44,941
Lance G. Johnson	32,531	Christian C. Michel	46,300

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Direct all correspondence to: ☐ Customer Number or Bar Code Label ______ *OR* ☑ Correspondence address below

Name	John E. Holmes				
Address	Roylance, Abrams, Berdo & Goodman, L.L.P.				
Address	1300 19th Street, N.W., Suite 600				
City	Washington	State	D.C.	ZIP	20036
Country	USA	Telephone	(202)659-9076	Fax	(202)659-9344

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Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Ernst	Eberlein

Inventor's Signature						Date	11/21/00
Residence: City	Grossenseebach	State		Country	Germany	Citizenship	German
Post Office Address	Waldstrasse 28 b DEX						
Post Office Address							
City	Grossenseebach	State		ZIP	D-91091	Country	Germany

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ADDITIONAL INVENTOR(S)
Supplemental Sheet
Page 1 of 2

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])				Family Name or Surname			
Sabah				Badri			
Inventor's Signature	S. Badri					Date	11/22/00
Residence: City	Erlangen	State		Country	Germany	Citizenship	Moroccan
Post Office Address	Sebaldusstrasse 8 DEX						
Post Office Address							
City	Erlangen	State		ZIP	D-91058	Country	Germany

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])				Family Name or Surname			
Stefan				Lipp			
Inventor's Signature	S. Lipp					Date	11/22/00
Residence: City	Erlangen	State		Country	Germany	Citizenship	German
Post Office Address	Steinweg 9 a DEX						
Post Office Address							
City	Erlangen	State		ZIP	D-91058	Country	Germany

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])				Family Name or Surname			
Stephan				Buchholz			
Inventor's Signature						Date	
Residence: City	Muenchen	State		Country	Germany	Citizenship	German
Post Office Address	Kerschlacher Strasse 8						
Post Office Address							
City	Muenchen	State		ZIP	D-81447	Country	Germany

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Supplemental Sheet
Page 1 of 2

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])				Family Name or Surname			
Sabah				Badri			
Inventor's Signature						**Date**	
Residence: City	Erlangen	**State**		**Country**	Germany	**Citizenship**	Moroccan
Post Office Address	Sebaldusstrasse 8						
Post Office Address							
City	Erlangen	**State**		**ZIP**	D-91058	**Country**	Germany

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])				Family Name or Surname			
Stefan				Lipp			
Inventor's Signature						**Date**	
Residence: City	Erlangen	**State**		**Country**	Germany	**Citizenship**	German
Post Office Address	Steinweg 9 a						
Post Office Address							
City	Erlangen	**State**		**ZIP**	D-91058	**Country**	Germany

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

4-00

Given Name (first and middle [if any])				Family Name or Surname			
Stephan				Buchholz			
Inventor's Signature	Stephan Buchholz					**Date**	11/20/00
Residence: City	Muenchen	**State**		**Country**	Germany	**Citizenship**	German
Post Office Address	Kerschlacher Strasse 8 DEX						
Post Office Address							
City	Muenchen	**State**		**ZIP**	D-81447	**Country**	Germany

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Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Albert	Heuberger

5-00

Inventor's Signature	Albert Heuberger					Date	11/21/00
Residence: City	Erlangen	State		Country	Germany	Citizenship	German
Post Office Address	Hausaeckerweg 18 DEX						
Post Office Address							
City	Erlangen	State		ZIP	D-91056	Country	Germany

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Heinz	Gerhaeuser

6-00

Inventor's Signature	Heinz Gerhaeuser					Date	11/21/00
Residence: City	Waischenfeld	State		Country	Germany	Citizenship	German
Post Office Address	Saugendorf 17 DEX						
Post Office Address							
City	Waischenfeld	State		ZIP	D-91344	Country	Germany

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname

Inventor's Signature						Date	
Residence: City		State		Country		Citizenship	
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